

EFFECTS OF SLASH DISPOSAL PRACTICES IN  
LODGEPOLE PINE ON SOIL WATER  
CHEMISTRY USING CERAMIC  
CUP SAMPLERS

by

Robert W. Hennes and George E. Hart

Completion Report submitted to  
U. S. Forest Service  
Intermountain Forest and Range Experiment Station  
Logan, Utah

Funded under  
Master Memorandum of Understanding  
12-11-204-3  
Supplements 33, 48, and 74

April 1979

INT-Logan

1377

March 30, 1979

REPLY TO: 4040 Cooperation

SUBJECT: Supplements 33, 48, and 74, Utah State University



TO: David Blackner, AD, INT

*Effects of slash disposal*

Enclosed is one completion report that covers the cooperative research done by George Hart and others at Utah State University to fulfill the requirements of Supplements 33, 48, and 74 to the Master Memorandum of Understanding 12-11-204-3. I have reviewed the report and find it entirely satisfactory. It meets and, thus, completes all of the objectives set forth in these three Supplements.

Earlier progress reports have, I believe, met the administrative requirements for Supplements 33 and 48. I believe the University has been fully reimbursed for expenses associated with these two. You might check this, though, to make certain that my assumptions are correct. Your release of the final 15% of the funds set up in Supplement 74 is contingent upon receipt and acceptance of this report. Here is the report that I have accepted. You may now release the last 15% of this money to USU.

Unless you have a real need for it, I suggest that this copy of the report be either given to Blaisdell or be filed in the Station-Region library. The Forest Service has six copies--two are being sent to Ron Barger, three remain here, and you now have one.

*Norbert V. DeByle*  
NORBERT V. DEBYLE  
Plant Ecologist

Enclosure

cc: George Hart  
Ron Barger  
Walt Mueggler

DEPARTMENT OF FORESTRY AND OUTDOOR RECREATION

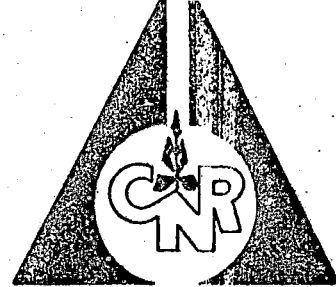
College of Natural Resources

UMC 52

Utah State University

Logan, Utah 84322

29 March 1979



752-4100 Ext. 7845

Dr. Norbert DeByle  
Forestry Sciences Lab  
UMC 80  
Campus Mail

Dear Norb:

It is with great pleasure and relief that I am sending 6 completion reports on the combined projects:

Effects of slash disposal practices on the chemistry of soils and subsurface water (Supplement 33 to 12-11-204-3)

Chemistry of soil solutions (Supplement 48 to 12-11-204-3)

Test of soil solution samplers under field and lab conditions (Supplement 74 to 12-11-204-3)

Would you please acknowledge receipt of the reports and completion of the project by signing below and returning copies to: 1) Controllers Office, UMC 24 (Mrs. Pierre), 2) Contracts Office, UMC 14, 3) me.

As you know, it has been a long task, but I think the basic findings on the field and lab aspects are worthwhile and worthy of publication. I've enjoyed working with you and believe that this project has led to a stronger cooperative arrangement between the Intermountain Station and our Department.

Sincerely,

*George E. Hart*  
George E. Hart,  
Associate Professor

GEH:gg

I have received completion reports for the above projects and certify that they are satisfactorily completed.

*Norbert V. DeByle*  
Norbert V. DeByle

30 MAR 1979

Date



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January 1979

## ACKNOWLEDGEMENTS

In 1971, a project was initiated by the Intermountain Forest and Range Experiment Station to study the effects of selected slash treatments on subsurface water chemistry. Data from this project, under the direction of George E. Hart and Norbert V. DeByle, was used in this thesis. The performance of ceramic cups for taking soil solution samples was studied in another project which also was financed by the Intermountain Forest and Range Experiment Station. Without the continual support, availability, interest and enthusiasm, as well as sincere friendship given to me by Dr. Hart, this research and thesis would not have been possible.

Several people in various university departments gave their time and facilities in support of this research. Departments offering the use of their facilities included the Departments of Chemistry, Biology, Soils and Biometerology, and Engineering. Special thanks is given to Dr. Ruele Lamborn in the Soil Testing Laboratory for the use and instruction on the atomic absorption spectrophotometer. Dr. Slavin Southard, of the Soils and Biometerology Department, assisted in the installation of the field instrumentation as well as provided soil profile classifications for the research area.

In 1978, the evaluation of the ceramic cups was performed at the Utah Water Research Laboratory. Dr. V. Dean Adams graciously donated

time and space as well as instrument time and instruction. Without this support from Dr. Adams, the second part of the thesis would have been impossible.

The first part of the project was performed on the Bridger-Teton National Forest. Throughout the several years of the project, the Forest offered total cooperation as well as housing while doing the field work, which I deeply appreciated.

While I undertook this research I was fortunate to have a committee who was helpful and interested in the research from the start; Dr. Jerome Jurinak, who helped design the second part of the research; Dr. Norbert DeByle, who assisted throughout the project and contributed the photos used in the first section of the thesis; and Dr. V. Dean Adams, who helped interpret the analytical data and chemical procedures. Of course, each member of the committee offered suggestions and were always helpful.

Finally, I would like to thank the family of Dr. George Hart for their friendship throughout my time spent in Logan. The special warmth and hospitality given to me will always be felt and remembered.

Robert Wayne Hennes

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## ABSTRACT

Effects of Slash Treatments on Soil-Water  
Chemistry Using Ceramic Cup Samplers

by

Robert Wayne Hennes, Master of Science

Utah State University, 1979

Major Professor: Dr. George E. Hart  
Department: Forestry and Outdoor Recreation

In a field study in western Wyoming, soil water samples were collected under several slash treatments. The study area, located at an elevation of 9500 feet, consisted of several clearcut units upon which the slash had been chipped, removed, broadcast burned or windrow burned. Thirty-two samplers were installed under the treatments and in an undisturbed forest. Samples were collected approximately four times a year from 1972 through 1977. Water samples were analyzed for calcium, magnesium, sodium, potassium, nitrate-nitrogen, phosphates, acidity, specific conductance, and total phenols. Yearly mean values and yearly maximum values for samples collected beneath the treatments were compared with those from the undisturbed forest. Monovalent cations (sodium and potassium) showed little or not increases in concentrations after clearcutting and slash treatment, while the bivalent cations (calcium and magnesium) increased markedly after clearcutting. Calcium concentrations were approximately double those in the undisturbed forest. Magnesium showed similar increases.

Nitrate-nitrogen levels increased under all treatments and reached levels as high as 20 mg/l. Samples from the undisturbed forest never were greater than 2 mg/l  $\text{NO}_3\text{-N}$ . Increased phenols were noted in areas where chips were spread, as well as in the cleared areas. Under the chips, soil water contained levels of total phenols as high as 1.450 mg/l. No increases in phenols were noted in treatments where slash had been burned. Changes in soil water chemistry occurred in all treatments. Most changes were of short duration, lasting only a few days after treatment. The chipped treatment, however, caused alterations in soil water chemistry which lasted longer than the other treatments. Broadcast burning appeared to be the best method of slash disposal because of the diffuse impact of the burning over the entire area.

In a lab study of ceramic soil water extraction cups, the effect of previous field use and pretreatment techniques on sample concentrations were evaluated. In one series of tests extractions from old cups were compared to those from new cups which had been flushed with dilute hydrochloric acid and distilled water. Consistently, samples collected with old cups were higher than those extracted by new cups. In another series of tests, old and new cups were uniformly flushed with dilute acid and rinsed before sampling a known nutrient concentration. After treatment, tests showed similar performance between old and new cups. After cups were rinsed and flushed, true concentrations were underestimated by 6 to 30 percent. In subsequent samples, this difference decreased. The data suggest that, when



sampling dilute solutions, the unsatisfied cation exchange capacity causes the first samples collected to underestimate the ionic concentrations of the soil water solution.

(142 pages)

PART I

EFFECTS OF SLASH DISPOSAL TREATMENTS IN  
LODGEPOLE PINE ON SOIL-WATER CHEMISTRY

## INTRODUCTION

It has been demonstrated that most economical timber harvesting and better natural regeneration rates occur when clearcutting methods are utilized on old growth lodgepole pine (Pinus contorta Dougl.) stands in Wyoming. In overmature stands, harvest residue can reach levels approaching 50 percent of the total volume of the timber stand (Foulger and Harris 1973). Currently, much concern over site appearance and environmental impact has prompted investigation into increased utilization of the harvest residues and different methods of slash disposal.

Slash disposal has been shown to cause an alteration of water quality leaving a clearcut site (U.S. Dept. of Agriculture 1974). Several techniques have been used, with burning traditionally being the most popular. However, burning may release nutrients for rapid leaching through the soil profile and excessive losses from the site.

Alternatives to burning are now being investigated, such that greater utilization of slash could be accomplished, changes in site appearance could be minimized, conditions for regeneration could be improved, and resultant changes in nutrient concentrations leaving the site could be reduced.

In 1971, a cooperative study was developed, involving the U.S. Forest Service (Intermountain Forest and Range Experiment Station; Bridger-Teton National Forest; and the Forest Products Laboratory), the U.S. Plywood-Champion Paper Company, and the Department of Forestry and Outdoor Recreation at Utah State University. The study was

developed to investigate alternative methods of slash disposal and utilization in old-growth lodgepole pine stands in western Wyoming. The first 3 years of data have been summarized (Hart and DeByle 1975). The entire 6 years of data on the effects of the various methods for disposing of logging debris on the chemistry of subsurface soil-water are evaluated in this paper.

## LITERATURE REVIEW

### Effects of Timber Harvesting on Water Quality

Several researchers have studied the impact of timber harvest on nutrient losses from forest ecosystems. These studies demonstrate the influence of different environmental conditions on the extent of nutrient losses.

The most dramatic impact of clearcutting was seen at the Hubbard Brook Experimental Forest in New Hampshire, where a small watershed with northern hardwoods was cut in 1965. All slash, as well as merchantable timber, was left in place after cutting. During the following summer, all regrowth was inhibited by aerial application of a soil herbicide. 2-4-D was also applied by handspraying individual resprouts for 3 years. After clearcutting, runoff increased 40 percent. Nitrate-nitrogen ( $\text{NO}_3\text{N}$ ) concentrations increased from 1 to 80 mg/l, and cation losses increased 9, 8, 3, and 20 times for calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), respectively. Of all major ions in solution, only sulfates were seen to appreciably decrease in concentration after treatment (Likens et al. 1970).

Nutrient outflow was also shown to increase in a series of clearcuttings near the Hubbard Brook Experimental Watershed, where conventional logging practices were followed and regrowth occurred naturally (Pierce et al. 1972). Nitrates were increased about

23 mg/l above values observed on an uncut watershed. Major cations increased after cutting, but to only one-third to one-half of the increases noted when the watershed was completely denuded.

Research done on the H. J. Andrews Experimental Forest in the Oregon Cascades on old growth Douglas-fir forest (Fredriksen 1971) demonstrated impacts of logging and slash burning on resultant water quality. The concentration of cations increased from 1.6 to 3 times that of the control watershed. Concentrations of ammonia and manganese exceeded federal drinking water standards for 12 days following slash burning.

- In another study of clearcutting followed by slash burning in Oregon, on the Alsea Watershed in the Oregon Coast Range (Brown 1974), nitrate-nitrogen concentrations and potassium levels increased only slightly over pretreatment levels. All other elements showed essentially no increase.

In an early study on the Cedar River Watershed in Washington (Gessel and Cole 1965), total elemental movement through the soil, sampled within the profiles by tension lysimeters, increased immediately after clearcutting, although only slightly. Most elemental movement was noted in the fall. However, in the drainage water, concentrations of elements actually decreased due to dilution from higher flow.

In a later study in the same area (Grier and Cole 1971), concentrations of major ions were measured in samples obtained by tension lysimeters following slash disposal by broadcast burning. This study concluded that;



1. Burning caused substantial increases in the concentrations of ions entering the soil.

2. Leaching from the root zone increased.

3. Leaching of ions in the ash layer caused major changes in the soil chemistry.

4. Most ions leached out in the ash layer were absorbed in the A and B horizons.

5. The major cation in the ash was calcium, but potassium was the major cation leached from the ash layer, with magnesium being the major cation leaving the rooting zone.

Nutrient losses were also examined on the Fernow Experimental Forest in West Virginia (Aubertin and Patric 1974). An 85 acre watershed was conventionally clearcut and natural regeneration occurred rapidly. Unlike the New Hampshire experiments, concentrations of dissolved solids remained virtually unchanged in the streamflow. Nitrates remained well below drinking water limits. This contradiction in results with the original Hubbard Brook experiments was attributed to different soil types, much greater vegetative density and recovery at Fernow, and buffer strips along streams.

Limited research at the Coweeta Hydrologic Laboratory in North Carolina (Douglass and Swank 1975) has shown that major changes in vegetative cover on a forested watershed have resulted in only minimal changes in cation concentrations and nitrate levels. The authors also cite unpublished data from other studies in North Carolina which support their findings.

Overland flow was collected from control plots and plots which were clearcut and prescribed burned in a forest of larch and Douglas-fir in western Montana (DeByle and Packer 1972). After burning, the total dissolved solids (TDS) in runoff water from the treated plots was twice that from the control forested plots. However, total dissolved solids concentrations returned to pretreatment levels 1 year after treatment. The authors concluded that within a few years potential nutrient losses would be negligible except possibly from a high intensity summer rain storm. Although they did not investigate the nutrient losses passing through the soil profile, the authors assumed that the soil type would be such that all major cations would be retained on the soil complex and not lost through deep percolation. Total losses from clearcutting were estimated at 2.1 percent, 0.5 percent, 1.1 percent, 1.5 percent, and 0.6 percent of total available sodium, phosphorus, potassium, magnesium, and calcium, respectively (DeByle 1976). It would require at least 50 forest rotations to fully remove all available sodium, assuming no incoming nutrients through precipitation or weathering of the bedrock. The amount of nutrients lost to the site through overland flow represented a negligible amount of loss to the system, and posed no threat to resultant water quality.

A summary of current knowledge on residue and disposal is given in Environmental Effects of Forest Residues Management in the Pacific Northwest, a state of knowledge compendium (U. S. Dept. of Agriculture 1974).

In a discussion of effects on water quality, several different variables were mentioned by Rothacher and Lopushinsky (1974) in relation to cation losses from clearcut watersheds. They cite the work of McColl and Cole (1968) which suggest that increased cation losses are a result of increased bicarbonate ( $\text{HCO}_3^-$ ) levels due to microbial activity. Apparently, bicarbonate is the principal anion in soil-water, and cation activity was a direct function of  $\text{HCO}_3^-$  concentration. Release of chemicals also may be due, in part, to the marked decrease in vegetation available to utilize the chemical after logging. Rothacher and Lopushinsky further stated that chemical release by slash is a function of slash size, vegetative uptake, cation exchange capacity (CEC) of the soil, and availability of water to transport the mobile chemicals. Finally, they conclude that fires create the conditions most likely to make large quantities of chemicals more soluble to leaching processes and eventual degradation of stream water quality.

Soil parent material and topography can have a substantial impact on the amount of nutrients lost from a forest ecosystem (DeByle 1976). Soil with a low CEC will be markedly altered in chemistry, as was seen in the Hubbard Brook experiments mentioned earlier, where shallow, acid soils overlie a nonpermeable lithic contact. DeByle suggests that shallow sandy soils, with low CEC, in humid climates, would react the same way. After burning, nutrients which would be in a highly soluble and mobile state could move rapidly with incoming

soil-water. However, deep soils with a high clay content and therefore higher CEC would be expected to retain higher amounts of nutrients made available by clearcutting and burning.

The studies mentioned above demonstrate the range of nutrient losses noted after clearcutting. This range is a function of climate, soil type, amount of vegetation removed and rate of regrowth. Therefore, the impact of timber harvesting on water quality should be considered a site specific property and no generalizations should be applied to all forest situations.

### Slash Treatments

Amounts of slash remaining after harvesting are often a function of the amounts of old growth timber in the stand. Four major categories of residue treatment have been recognized (Jemison and Lowden 1974):

1. No treatment, i.e., all slash is left onsite.
2. Rearranged, such as piles or mechanically treated, such as chipping, lopping and scattering.
3. Removal of slash from the site with treatment disposal elsewhere.
4. Burning, either in piles, windrows, or broadcast.

In areas where slash does not present a substantial fire hazard or displeasing appearance, it is often left in place and not treated. However, in areas where amounts of slash are considerable, it can represent an unacceptable fire or insect hazard.

Mechanically treating or rearranging slash requires heavy equipment in conjunction with crawler tractors, and therefore mechanical treatment has been limited to use only in areas with slopes of 35 percent or less. Where mechanical treatment such as chipping is possible, it is often costly. Chipping can result in a layer of spread chips which in themselves can reduce the availability of soil nitrogen, and impede seedling regeneration (Environmental Protection Agency 1976). However, chipping can also reduce soil loss due to erosion as well as limit the amount of soil compaction resulting from rainfall impact.

Broadcast burning often does not require the amount of heavy equipment needed in mechanical treatment of slash, and therefore results in less soil compaction on the site.

Selection of the best method of slash treatment is based on a complex set of concerns, including economics and potential fire and insect hazard. Other concerns are the aesthetics after treatment and the environmental impact of treatment, such as smoke and water quality. However, the impact on water quality, especially soil-water chemistry, has been only minimally investigated.

## OBJECTIVES

More complete utilization of logging residues could markedly alter the chemistry of soil-water. With this change in nutrient status in the soil could develop a changed environment for seedling regeneration. Water yields from the site could be changed in composition as well. It is the objective of this study to determine the effect of four slash disposal practices on the chemistry of subsurface soil-water, including:

1. Pile and burn;
2. Broadcast burn;
3. Mulching with chips; and
4. Total removal of residue.



## SITE DESCRIPTION

### Location and Size

The study was located in four clearcut units near Union Pass on the Continental Divide on the Bridger-Teton National Forest near Dubois, Wyoming (Figure 1). The units each occupied approximately 20 acres. Slopes ranged from 5 to 22 percent. Three of the four units were contiguous at an elevation of 9,500 feet. One unit was located about 1 mile north at an elevation of about 9,200 feet.

### Soils

Soils in all plots were characteristically loams, with platy structure near the surface. With depth, the soils become coarser in texture and grade into sandy and gravelly loams. The pH of the soils ranges from 5.0 to 5.7 and the cation exchange capacity ranges between 12 and 18 meq/100 grams of soil, with the CEC decreasing by half with depth. Representative pedons have been described by Dr. Alvin Southard and laboratory analysis of soil chemistry as well as particle size distributions for all plots are shown in the Appendix,

### Climate

The climate is considered to be sub-alpine. Although no climatic data have been collected on the site itself, total yearly precipitation was estimated from isohyetal maps of the area to be 30-40 inches per year. Precipitation is mostly in the form of snow, with a snowpack accumulating from late September through April. Rain

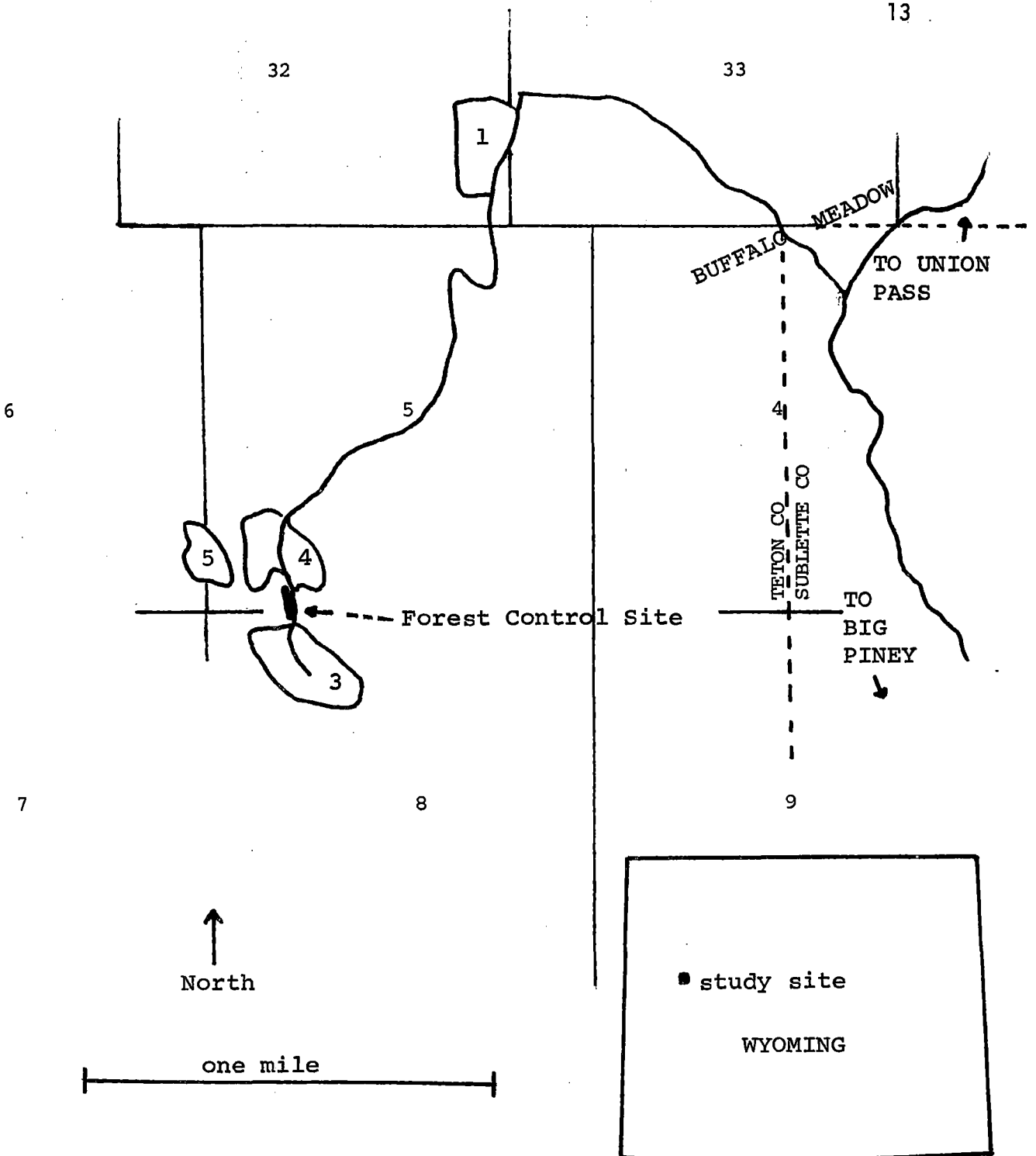


Figure 1. Relative positions of study units.

events in summer are usually of low intensity. Occasionally high intensity, short duration convective storms contribute to summer precipitation.

### Vegetation

Before harvesting, lodgepole pine (Pinus contorta Dougl.) represented from 75 percent to 90 percent of the total timber volume. Other species which made up the remaining volume included Englemann spruce (Picea engelmannii Parry) and subalpine fir (Abies lasiocarpa Hook), as well as a small amount of limber pine (Pinus flexilis James) (Foulger and Harris 1973). Average age of the stand was 175 years. Estimated volume of the stand, to a 6-inch top, was about 7,200 cubic feet per acre, and consists of approximately 85 percent live material and 15 percent dead stand.

### Treatment

In 1971 three units of approximately 20 acres each were clearcut. One unit (number 3) was clearcut using conventional standards in the Intermountain Region. The trees were felled and limbed using chainsaws, cut to a 6-inch top, merchantable logs were tractor skidded in tree lengths to logdecks and removed from the site. In 1974 conventional clearcutting was applied to another unit (number 5) adjacent to Unit 3.

In late 1971, Unit 3 was divided into quadrants and slash on two of the quadrants of Unit 3 was windrowed and burned (Figure 2). In June 1973 the other two quadrants of Unit 3 were broadcast burned (Figure 3). Burn intensity on Unit 3 was considered light. In 1974



Figure 2a. Windrow burn (Unit 3). Concentrated debris produced a high intensity burn.



Figure 2b. Windrow burn. After burn conditions. Note amount of ash remaining.



Figure 3a. Broadcast burn on Unit 2 in foreground. Remaining coarse material is uniformly dispersed over area. Chopped and bare areas of Unit 1 in background.



Figure 3b. Broadcast burn. Soil-water sampler shown in foreground.

the slash on Unit 5 was windrow burned. This burn was believed to be of considerably higher intensity than on Unit 3.

In Units 1 and 4 "near complete" utilization techniques were applied. Trees were felled with a Drott Feller-Buncher. All standing live trees, 3 inches DBH or greater and all down trees 6 inches or greater DBH, were removed. A rubber-tired Timberjack skidder hauled entire trees to the deck. Here the sawlog portions were cut and all remaining volume, excluding the remainder of the top, limbs, and foliage was chipped in a Morbark Chiparvester. Both Units 1 and 4 were subdivided into quadrants. On both units, half the area was left bare (Figure 4), and in the fall of 1972 the other half of the units were covered with the chips to a depth of roughly 6 inches resulting from the "near complete" harvesting technique (Figure 5).





Figure 4. Bare site (Unit I). Some slash remained on site.

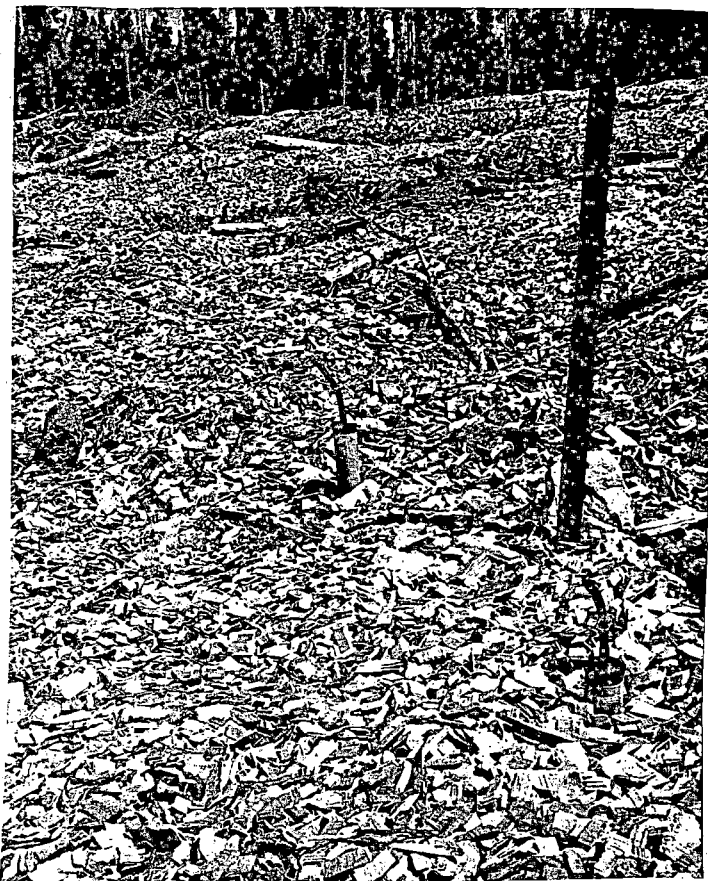


Figure 5. Chipped site (Unit I). Coarse textured chips spread about 1/2 foot deep.

## METHODS

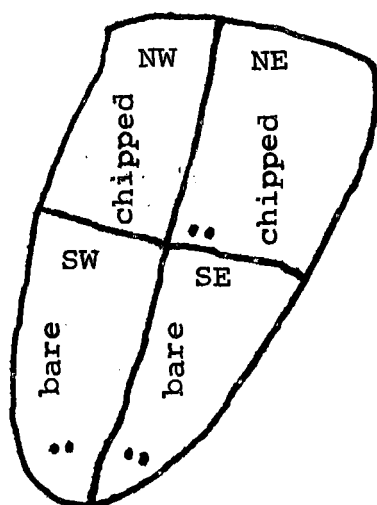
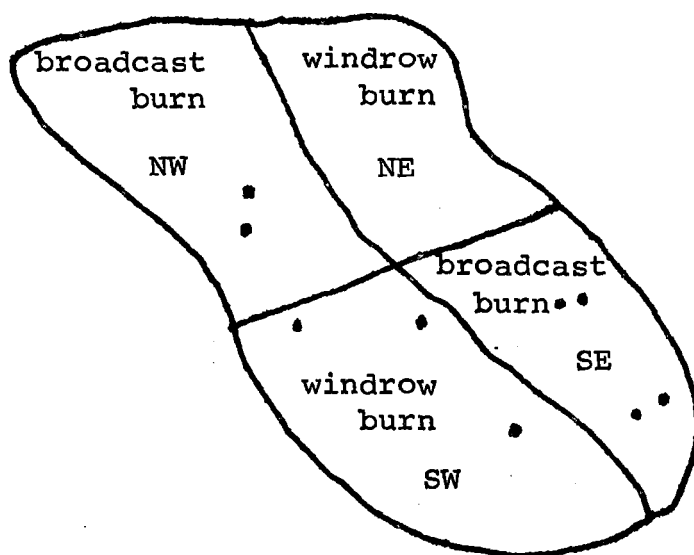
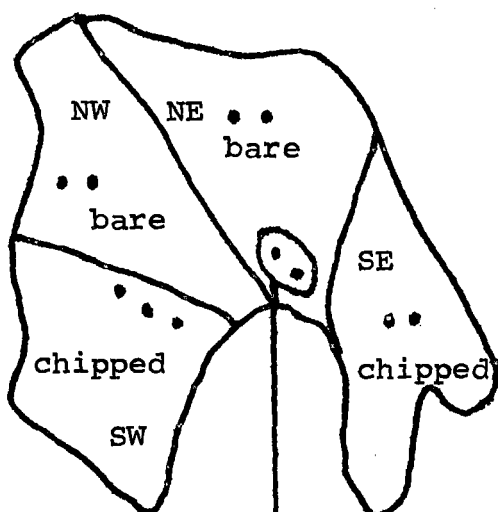
### Equipment

Soil solution samples were collected from the study areas using ceramic cup soil-solution samplers designed and built by the Soil Moisture Equipment Company. All cups were pretreated with one-normal hydrochloric acid and distilled water to leach out soluble contaminants in the cup matrix (Grover and Lamborn 1970). Each sampler consisted of a ceramic cup sealed to a piece of 2-inch diameter PVC tubing. A soil auger was used to insert the tubes to depths of 2 feet and 4 feet.

### Sampling Locations

In June 1972, 32 samplers were installed in Units 1, 3, 4, and the undisturbed forest control site. Eight samplers were installed in the bare sites, where most of the slash had been removed. Each pair of samplers in each quadrant consisted of one tube at a 2-foot depth and one at a 4-foot depth (Figure 6).

Nine samplers were installed in areas where residue had been chipped and spread. In Unit 1, two tubes were installed in the NE quadrant. In Unit 4, two tubes were installed in the SE quadrant and three in the SW quadrant. Two tubes were originally in an area characterized as "bare" (NE quadrant), but were in actuality found to be in a chipped area due to spillage of chips transported up to the SW quadrant. These samples were included with data from other tubes in the chipped sites.

Unit 1Unit 3Unit 4

two tubes located in bare quadrant  
yet were covered with chips

Figure 6. Treatment layout on sites 1, 3, and 4, showing approximate locations of soil-water samplers.

Unit 3, which was conventionally logged, was used to compare broadcast burning with windrow burning. Three 2-foot tubes were placed in the SW quadrant, adjacent to the windrows. Six tubes were placed in the broadcast burn quadrants (NW and SE).

In late 1973 Unit 5 was conventionally logged. Slash was piled into windrows and burned in fall 1974. Sixteen samplers were installed in June 1975. Ten tubes (1 ft, 2 ft, and 4 ft) were installed beneath three windrows. Six tubes (1 ft, 2 ft) were placed between windrows in essentially bare areas.

Six tubes (3 pairs) were located in the forest control site. This site was located between Units 3 and 4 (Figures 1, 7). Table 1 summarizes the arrangement of samples in the various treatments.

#### Sampling Schedule, Collection and Storage

Soil-water was sampled 20 times, from June 1972 through August 1977. Samples were extracted three or four times each summer, beginning in June, at intervals of 2 to 4 weeks. The initial sampling date was usually a function of accessibility to the sites which was determined by the amount of snowpack remaining on the sites at the beginning of the summer.

Suction was applied to all samplers on the initial visit to the site and samples were collected on the following visit; suction then was reapplied for the next sampling period. The samples remained in the sample tubes for the 2 to 4 weeks between visits to the sites.



Figure 7. Undisturbed forest site, showing high proportion of down stand.

Table 1. Location of samplers.

Treatment	Unit	Quadrant	Number of samplers at given depths		
			1 ft	2 ft	3 ft
Bare	4	NW	-	1	1
	4	NE	-	1	1
	1	SW	-	1	1
	1	SE	-	1	1
Chipped	4	SW	-	2	1
	4	SE	-	1	1
	1	NE	-	1	1
Broadcast burn	3	NW	-	1	1
	3	SE	-	2	2
Windrow burn	3	SW	-	3	-
	5	-	4	2	2
Between windrows	5	-	3	3	-
Forest control	-	-	-	3	3

Suction was applied to the sampling tubes using portable hand pumps and evacuated to approximately 0.5 atmospheres (15 inches of mercury). At the end of the sampling period, tubes were emptied using a suction inline trap system and collected in Nalgene 500 ml storage bottles. Samples were immediately sealed and refrigerated onsite. After collection from all sites, samples were transported to Logan, Utah for chemical analyses.

#### Chemical Analyses

Samples were analyzed for Na, K, Ca, Mg,  $\text{NO}_3\text{-N}$ ,  $\text{PO}_4\text{-P}$ , pH, specific conductance, and total phenols. All analyses (with the exception of phenols) were completed at Utah State University in the Soil Testing Laboratory and the Utah Water Research Laboratory. Total phenols were measured by the Ford Laboratory in Salt Lake City, Utah. All analyses were made according to Standard Methods (American Public Health Association 1971).

Sodium and potassium were measured using the flame emission mode of an atomic absorption spectrophotometer. Calcium and magnesium were measured using flame atomic absorption methods. Nitrates and phosphates were run colorimetrically, using the cadmium reduction and ascorbic acid methods, respectively. The pH and specific conductance were determined on a pH meter and conductivity bridge. Total phenols were analyzed colorimetrically using the chloroform extraction method.



## RESULTS

### Variability of Data

A great amount of variability occurred in the data within each treatment for most of the chemical parameters measured. As shown in Table 2, standard deviations were obtained which were as much as two and a half times as high as the mean for elements in low concentrations ( $\text{NO}_3\text{-N}$  and  $\text{PO}_4\text{-P}$ ). Reasons for this high variability are:

1. Physical inconsistencies of the treatment occurred throughout the sites. For example, in the "chipped" sites the depth of chips varied throughout the site. In the burned areas intensity was not uniform throughout the treatment. In the bare sites slash was not always entirely cleared from the area;

2. The number of observations varied from year to year because of sampler malfunction, dry conditions, and different numbers of yearly sampling periods. Consequently, one year's average was often based on a different population than the year before;

3. Samples were collected from 2-foot and 4-foot depths. Visual inspection of these data revealed high variability within samples collected at similar depths. Variations between samples collected at different depths were not consistent between sampling periods. Also, the soil horizons which corresponded to these depths varied between sites. In the final analysis, the data from the two depths are pooled.

4. Inconsistent times of sampling dates, suction times, soil moisture levels, laboratory storage times, and contamination from dead rodents in the sampling tubes all contributed to the variability.

The study units were clearcut in summer 1971 before the sampling tubes could be installed and therefore no pretreatment measurements were obtained. This weakened the experimental design for covariance analysis. Given the high inherent variability of natural ecosystems, the constraints of the ceramic cup samplers (see Part II), and the lack of experimental control, it did not appear productive to apply sensitive statistical tests to these data. After discussing this with Professor Hart and Dr. DeByle, the decision was reached to summarize the data in two ways. First, comparisons of yearly averages (and standard deviations) between treatments are shown in Table 2, and secondly, the maximum yearly values are compared in Table 3.

The first comparison allows observation of general trends noted within the treatments, as well as the amount of variability. The second comparison, based on yearly maximum concentrations, demonstrates more clearly the potential effects of the various treatments, as it focuses on the area where treatments have caused the most impact on nutrient transport throughout the soil-water system.

#### Validity of Chemical Data and Analyses

From 1971 through 1977, several different laboratories performed chemical analyses on samples taken in this project. Only in 1976 and 1977 did I personally perform the analyses.

Table 2. Yearly means and standard deviations of chemical parameters in mg/l.

Year	Na		K		Ca		Mg		NO <sub>3</sub> -N		PO <sub>4</sub> -P		Phenol		EC ( $\mu$ mhos/cm)		pH		Maximum number of samples
	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	
<u>Undisturbed forest control site</u>																			
1972	2.7	(1.8)	0.9	(0.6)	4.4	(1.3)	1.1	(0.2)	0.05	(1.10)	0.00	(0.00)	-	-	-	-	-	-	9
1973	1.3	(0.6)	0.6	(0.5)	2.9	(1.6)	0.8	(0.4)	0.08	(0.16)	0.01	(0.01)	0.010	(0.017)	51	(30)	5.4	(0.8)	25
1974	1.1	(0.3)	0.2	(0.2)	2.0	(0.5)	0.6	(0.3)	0.20	(0.10)	0.02	(0.05)	0.004	(0.007)	26	(3)	5.9	(0.5)	14
1975	1.0	(0.4)	0.4	(0.3)	1.4	(0.5)	0.4	(0.1)	0.12	(0.04)	0.01	(0.02)	0.000	(0.000)	25	(4)	6.6	(0.2)	14
1976	1.3	(0.5)	0.9	(1.0)	2.3	(0.5)	0.5	(0.2)	0.04	(0.05)	0.07	(0.18)	0.012	(0.009)	25	(4)	5.5	(0.2)	20
1977	1.3	(0.4)	0.6	(0.4)	2.3	(1.1)	0.6	(0.2)	0.18	(0.24)	-	-	-	-	35	(10)	-	-	18
<u>Bare</u>																			
1972	3.5	(2.7)	1.4	(0.5)	6.8	(3.7)	1.9	(1.0)	0.09	(0.16)	0.03	(0.08)	-	-	-	-	-	-	14
1973	3.0	(1.6)	1.2	(1.2)	7.0	(5.8)	1.8	(1.3)	1.46	(2.37)	0.07	(0.13)	0.659	(0.720)	85	(58)	6.0	(0.5)	27
1974	1.9	(1.3)	0.6	(0.5)	3.7	(2.5)	1.0	(0.7)	1.80	(2.90)	0.05	(0.09)	0.005	(0.006)	47	(28)	5.9	(0.6)	21
1975	1.2	(1.0)	0.6	(0.6)	2.2	(0.9)	0.6	(0.2)	0.40	(0.50)	0.04	(0.07)	0.000	(0.000)	30	(10)	6.9	(0.2)	27
1976	1.6	(1.0)	1.0	(0.7)	2.4	(0.7)	0.5	(0.2)	0.91	(1.33)	0.06	(0.09)	0.020	(0.024)	28	(10)	5.6	(0.2)	30
1977	1.4	(1.2)	0.8	(0.9)	3.2	(1.2)	0.7	(0.3)	1.39	(1.18)	-	-	-	-	38	(14)	5.6	(0.2)	20
<u>Pile and burn</u>																			
1972	2.4	(0.4)	0.6	(0.1)	5.0	(0.6)	1.4	(0.2)	0.10	(0.14)	-	-	-	-	-	-	-	-	2
1973	1.5	(0.6)	0.9	(0.5)	5.0	(1.1)	1.3	(0.3)	0.28	(0.40)	0.00	(0.00)	0.000	(0.000)	93	(114)	5.5	(1.0)	16
1974	1.0	(0.2)	0.4	(0.2)	3.9	(0.8)	1.3	(0.5)	1.05	(0.45)	0.01	(0.04)	0.000	(0.000)	49	(25)	5.3	(0.9)	7
1975	0.6	(0.2)	0.4	(0.1)	2.1	(1.0)	0.6	(0.3)	0.50	(0.40)	0.00	(0.01)	0.000	(0.000)	29	(10)	6.9	(0.3)	6
1976	0.9	(0.3)	0.6	(0.2)	3.0	(1.2)	0.7	(0.3)	0.75	(0.62)	0.01	(0.01)	0.007	(0.008)	29	(10)	5.4	(3.0)	11
<u>Broadcast burn</u>																			
1972	3.0	(2.2)	1.1	(0.6)	8.8	(10.1)	1.4	(2.1)	0.12	(1.10)	0.01	(0.01)	-	-	-	-	-	-	6
1973	1.5	(0.6)	1.6	(0.7)	9.7	(8.5)	2.5	(2.0)	0.30	(0.23)	0.21	(0.48)	0.030	(0.055)	184	(162)	4.5	(1.5)	13
1974	1.2	(0.5)	3.2	(5.1)	7.7	(8.7)	2.2	(2.1)	1.20	(1.80)	0.26	(0.17)	0.006	(0.007)	112	(150)	5.7	(0.9)	10
1975	0.6	(0.3)	1.0	(0.5)	2.0	(1.1)	0.7	(0.4)	0.72	(0.95)	0.04	(0.04)	0.000	(0.000)	36	(16)	6.7	(0.5)	11
1976	1.1	(0.4)	1.2	(0.4)	2.7	(1.4)	0.6	(0.4)	1.40	(1.60)	0.05	(0.05)	0.006	(0.010)	30	(14)	5.4	(0.4)	16
1977	1.5	(0.8)	1.1	(0.4)	4.4	(2.4)	1.2	(0.9)	4.00	(3.37)	-	-	-	-	57	(34)	-	-	12

Table 2. Continued.

Year	Na		K		Ca		Mg		NO <sub>3</sub> -N		PO <sub>4</sub> -P		Phenol		EC (μmhos/cm)		pH		Maximum number of samples
	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.	
Chips spread																			
1972	3.0	(2.5)	1.4	(0.9)	9.0	(6.3)	2.0	(1.4)	0.02	(0.04)	-	-	-	-	-	-	-	-	10
1973	2.2	(1.6)	1.9	(2.0)	10.3	(8.0)	2.5	(2.1)	0.52	(0.71)	0.02	(0.05)	0.622	(0.529)	100	(57)	5.7	(0.7)	30
1974	1.2	(0.4)	1.5	(1.4)	6.0	(3.2)	1.7	(0.8)	0.33	(0.36)	0.02	(0.06)	0.024	(0.045)	64	(42)	6.3	(0.8)	23
1975	0.8	(0.5)	1.7	(1.5)	6.4	(5.9)	1.4	(1.1)	0.38	(0.57)	0.05	(0.08)	0.001	(0.007)	47	(18)	6.7	(0.2)	25
1976	1.1	(0.5)	1.8	(1.5)	5.5	(3.2)	1.2	(0.6)	1.15	(1.78)	0.05	(0.06)	0.011	(0.012)	46	(18)	5.5	(0.1)	34
1977	0.9	(0.5)	1.5	(1.4)	5.9	(3.9)	1.6	(2.4)	2.23	(1.93)	-	-	-	-	54	(25)	-	-	24
Between windrows (Unit 5)																			
1975	0.9	(0.4)	1.0	(0.6)	4.0	(1.3)	1.1	(0.4)	0.33	(0.31)	0.01	(0.01)	0.001	(0.000)	58	(15)	6.2	(0.5)	12
1976	0.8	(0.2)	1.6	(0.6)	5.6	(3.8)	1.2	(0.5)	2.07	(2.30)	0.03	(0.04)	0.003	(0.008)	51	(18)	5.5	(0.3)	20
1977	0.7	(0.3)	1.6	(0.8)	4.8	(1.9)	1.2	(0.5)	2.70	(1.80)	-	-	-	-	57	(22)	-	-	21
Beneath windrows (Unit 5)																			
1975	2.3	(1.2)	1.9	(2.4)	11.0	(8.0)	3.0	(2.1)	0.66	(0.75)	0.00	(0.00)	0.004	(0.013)	118	(67)	6.6	(0.4)	21
1976	2.4	(0.8)	2.1	(2.1)	10.0	(4.5)	2.7	(1.2)	5.71	(5.96)	0.02	(0.02)	0.014	(0.022)	104	(38)	5.4	(0.2)	29
1977	2.2	(0.6)	2.1	(2.1)	17.8	(8.9)	4.3	(3.1)	9.50	(6.10)	-	-	-	-	149	(82)	-	-	26

Table 3. Yearly maximum concentrations in mg/l.

Year	Na	K	Ca	Mg	NO <sub>3</sub> -N	PO <sub>4</sub> -P	Phenol	EC (μmhos/cm)
<u>Undisturbed forest</u>								
1972	5.0	2.2	6.0	1.5	0.3	0.01	-	-
1973	3.0	2.2	6.5	1.9	0.8	0.04	0.030	145
1974	1.8	0.5	3.1	1.4	0.3	0.18	0.020	30
1975	1.4	0.8	2.4	0.6	0.2	0.05	0.000	34
1976	2.3	4.3	3.4	0.7	0.2	0.70	0.28	40
1977	2.4	1.4	4.4	0.9	0.9	0.05	-	48
<u>Bare</u>								
1972	11.2	2.5	15.3	4.4	0.5	0.21	-	-
1973	5.8	5.0	30.0	6.8	9.2	0.48	0.780	316
1974	5.0	1.8	11.3	3.2	11.4	0.34	0.013	142
1975	4.1	2.6	4.8	1.1	2.5	0.20	0.001	53
1976	4.1	3.1	4.2	1.1	7.0	0.49	0.083	50
1977	4.3	1.7	4.4	1.1	3.4	0.10	-	58
<u>Pile and burn</u>								
1972	2.7	0.7	5.5	1.6	0.2	-	-	-
1973	2.5	1.9	7.0	1.9	1.8	0.00	0.000	511
1974	1.2	0.7	5.0	1.9	1.6	0.10	0.005	100
1975	0.9	0.6	3.1	0.9	1.0	0.02	0.001	39
1976	1.4	1.1	4.5	1.2	1.7	0.02	0.18	45
<u>Broadcast burn</u>								
1972	7.3	2.4	31.4	7.6	0.2	0.01	-	-
1973	2.8	2.7	34.6	7.6	0.7	1.35	0.100	534
1974	1.9	17.3	32.0	8.0	6.1	0.41	0.014	536
1975	1.2	2.0	4.4	1.5	2.6	0.14	0.000	58
1976	1.9	2.1	6.4	1.5	4.7	0.15	0.023	55
1977	3.5	1.8	9.0	3.1	11.7	0.15	-	124
<u>Chips spread</u>								
1972	9.5	3.6	22.9	4.5	0.1	0.00	-	-
1973	7.2	6.9	38.8	10.0	2.7	0.21	1.400	323
1974	1.9	4.8	15.0	3.3	1.6	0.31	0.165	240
1975	2.1	5.2	23.0	4.7	2.8	0.27	0.033	89
1976	2.4	5.8	14.2	2.5	9.0	0.25	0.034	80
1977	2.1	3.9	16.0	3.1	7.4	0.11	-	96
<u>Between windrows</u>								
1975	1.5	2.4	5.6	1.6	0.9	0.03	-	70
1976	1.1	2.9	19.7	2.3	5.8	0.16	0.018	90
1977	1.8	4.0	9.3	2.1	6.4	0.88	-	113
<u>Beneath windrows</u>								
1975	4.8	8.4	29.1	8.2	1.9	0.09	0.044	259
1976	4.0	8.0	18.8	5.2	20.0	0.09	0.050	166
1977	3.5	6.3	29.6	11.9	21.0	0.07	-	291

Some data from years before 1976 were omitted in the final summarization because of inconsistencies. Two conductivity measurements were reported to be approximately one order of magnitude higher than any other conductivity data found in the same treatment. Inspection of the concentrations of cations and anions showed no differences from other samples from the same treatment with lower conductivity levels. In this case, only the two conductivity data were discarded. In 1973, a pair of tubes located in the bare treatment produced samples with ionic concentrations several hundred times higher than samples collected from other tubes in the same treatment. Since no other tubes in the same treatment showed this magnitude of an increase, all data from this pair of tubes were discarded for the 1973 season. One possible explanation for these increases was animal contamination, as the concentrations of cations resembled urine. In 1977 several tubes were discovered to contain dead ground squirrels floating in the collected soil-water solution. These data were discarded.

Overall, only a small percentage of data was discarded. Only 12 samples out of over 600 were totally or in part eliminated.

#### Chemical Parameters

Sodium concentrations. In most slash treatments, increases of sodium were minimal, if at all, throughout the 6 years of record. Yearly mean values of sodium concentrations in the broadcast burn sites and the windrow burn (Unit 3) sites showed almost no change from the control. Only in the bare and chipped sites were maximum

values over twice the value of the control sites in the first 2 years after clearcutting alone (Figures 8 and 9). In 1973, after chips were spread over the treatment site, no additional increases were noted. However, within 1 year after treatment, concentrations in the chipped site showed no difference from the control site. In the bare sites, maximum concentrations remained slightly elevated throughout the 6 years, but the extent decreased in the last few years of sampling.

In the Unit 5 sites, which were burned in 1974, no changes in sodium concentrations were noted between windrows. Elevated levels were noted in the samples collected immediately beneath the windrows, with mean levels over twice as high as in the control site (2.3 mg/l vs. 1.0 mg/l).

These data indicated that none of the treatments alter the amount of sodium in the soil-water system. With the exception of one observation, all concentrations are well below 10 mg/l and represent very dilute sodium concentrations with no known toxicity.

Potassium concentrations. The data for potassium showed that some increases did occur in the treatment sites (Figures 10 and 11). The chipped site had elevated potassium levels following the application of chips in 1973. Following the application of chips, maximum values were almost five times the values observed in the forest control site, and this trend continued throughout the 6 years, with the differences in means diminishing in 1976 and 1977. Clearcutting also produced minimal increases. Both the windrow burn sites (Unit 3)

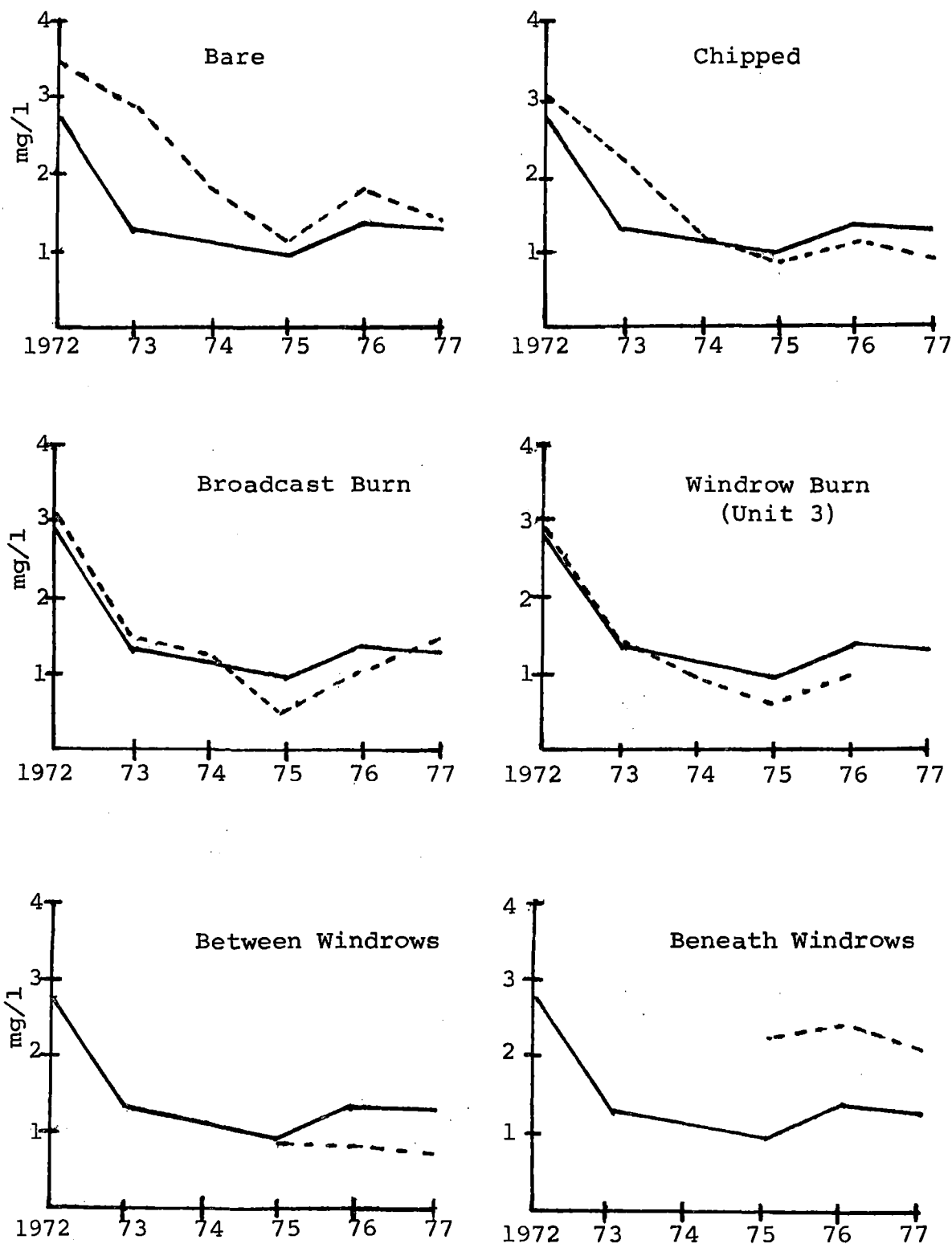


Figure 8. Yearly mean sodium concentrations; control (solid line) vs. treatment (dashed line).



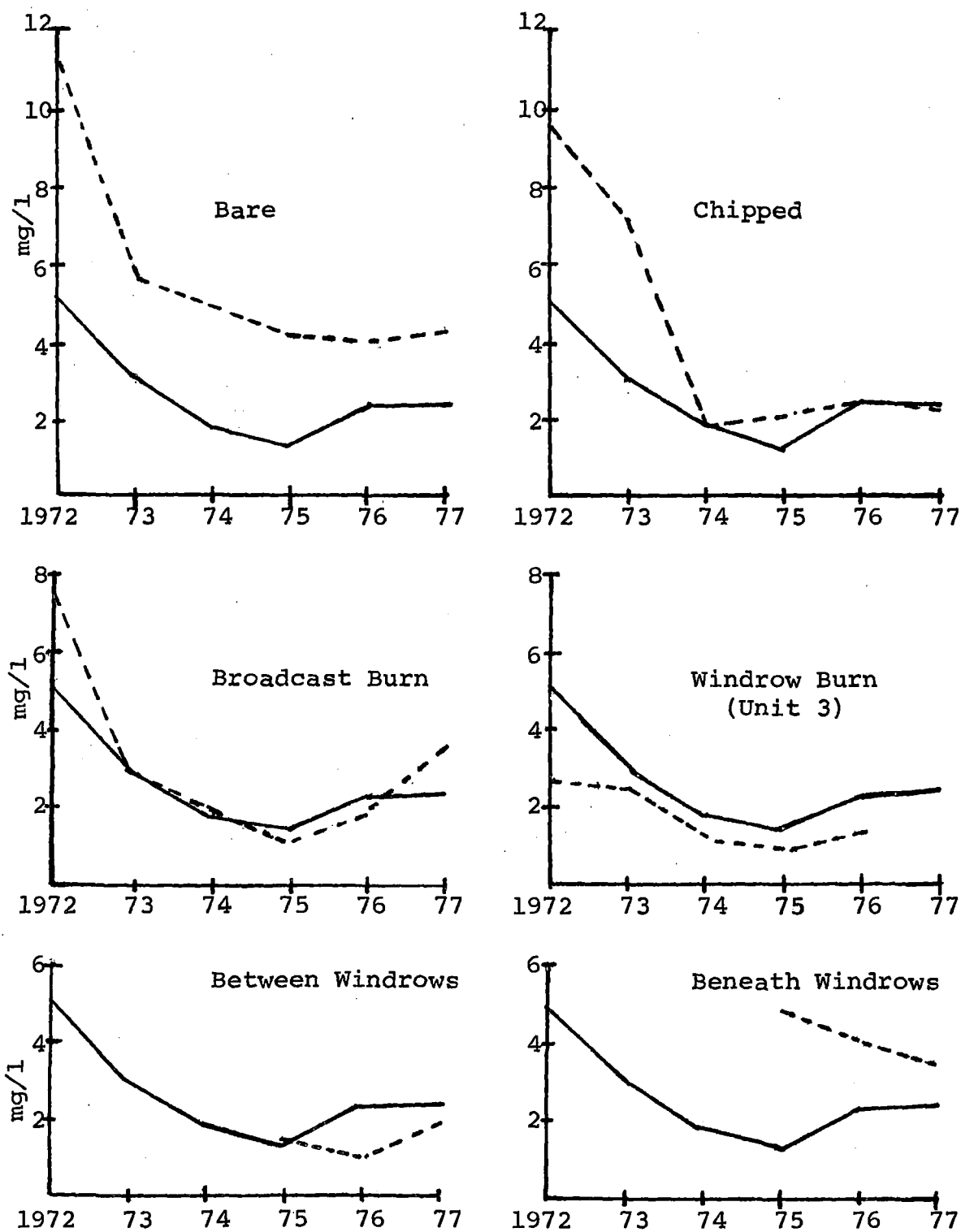


Figure 9. Maximum sodium concentrations; control(solid line) vs. treatment(dashed line).

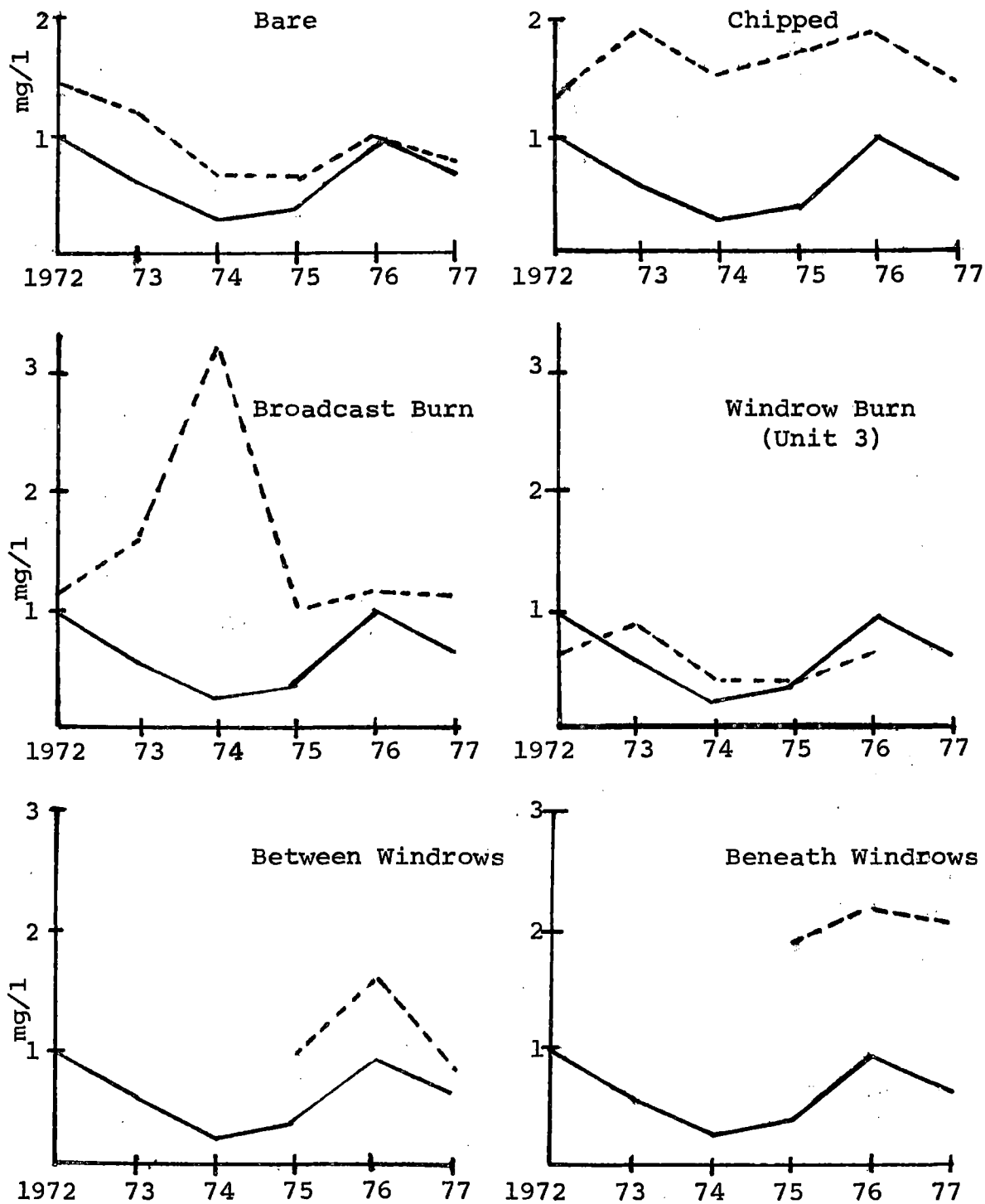


Figure 10. Yearly mean potassium concentrations; control (solid line) vs. treatment (dashed line).

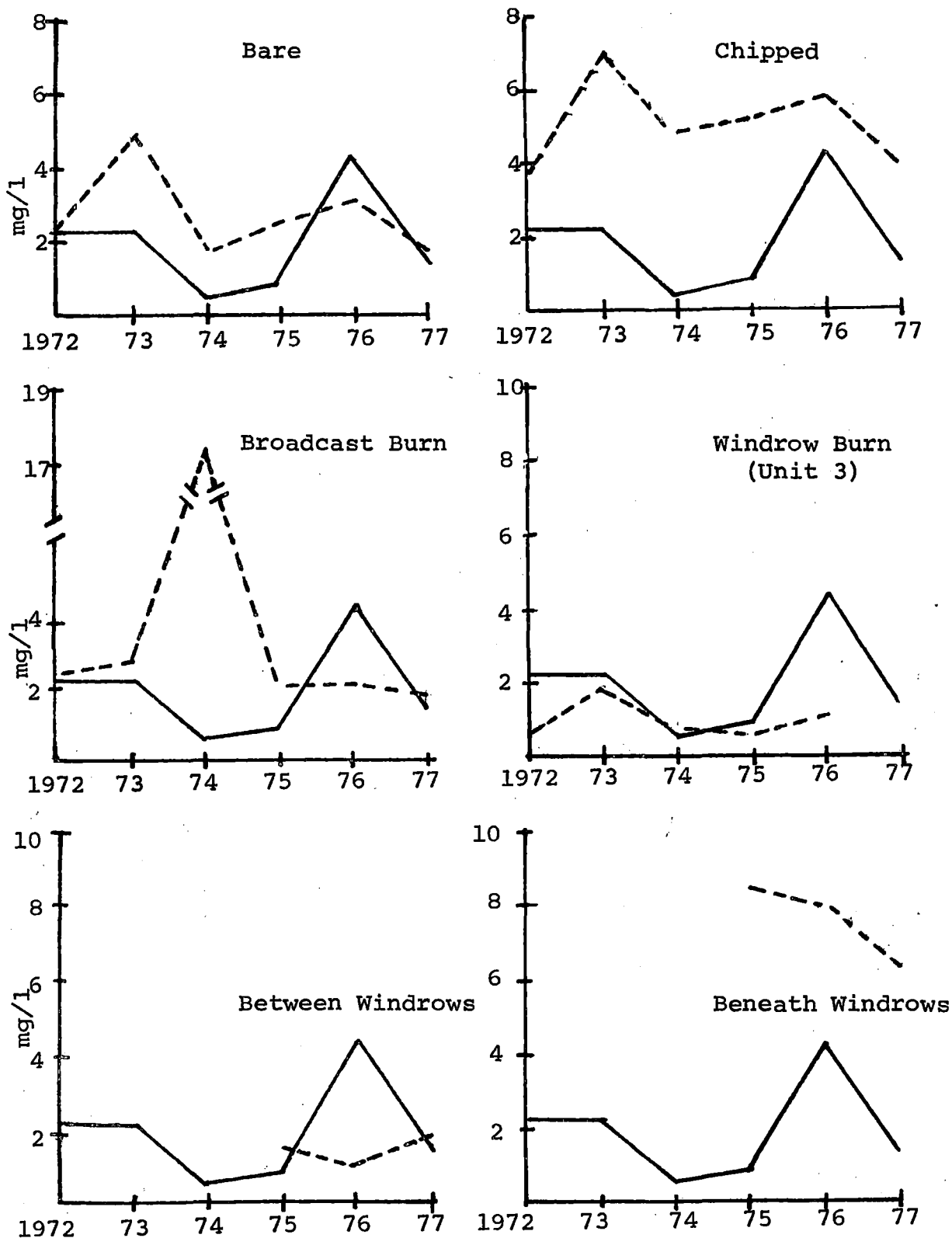


Figure 11. Maximum potassium concentrations; control(solid line) vs. treatment(dashed line).

and bare sites showed minimum effects of treatment throughout the sampling period.

In 1974 the broadcast burn sites showed an increase following the burn in 1973. Levels as high as 17.3 mg/l K were observed in one tube. However, the second highest value for the year was only 4.0 mg/l K, and by 1975 potassium levels were only slightly elevated. The Unit 5 beneath windrow sites showed maximum potassium levels in 1975 up to eight times higher than the forest control site. However, this difference decreased in 1976 and 1977. Between the windrows, no major change was noted between the treatment and the control site.

As noted in sodium, all potassium concentrations were below toxicity levels, remaining below 10 mg/l K (with the exception of one observation) throughout all treatments.

Calcium concentrations. As compared to the monovalent cations discussed above, calcium concentrations showed more marked increases on the treated sites. Clearcutting alone caused calcium concentrations to approximately double in the bare, chipped and broadcast burn sites. Following the application of these slash treatments, these sites showed increases in maximum concentrations to above 30 mg/l Ca (Figure 13). In the bare and broadcast burn sites, this five-fold increase above the forest control site rapidly diminished with time. But, in the chipped sites, the elevated Ca levels prevailed throughout the study. Again, the windrow burn site (Unit 3) showed only slightly elevated levels when compared to the control site (Figures 12 and 13). On the Unit 5 plots similar elevated calcium concentrations were noted after treatment, primarily underneath the windrows.

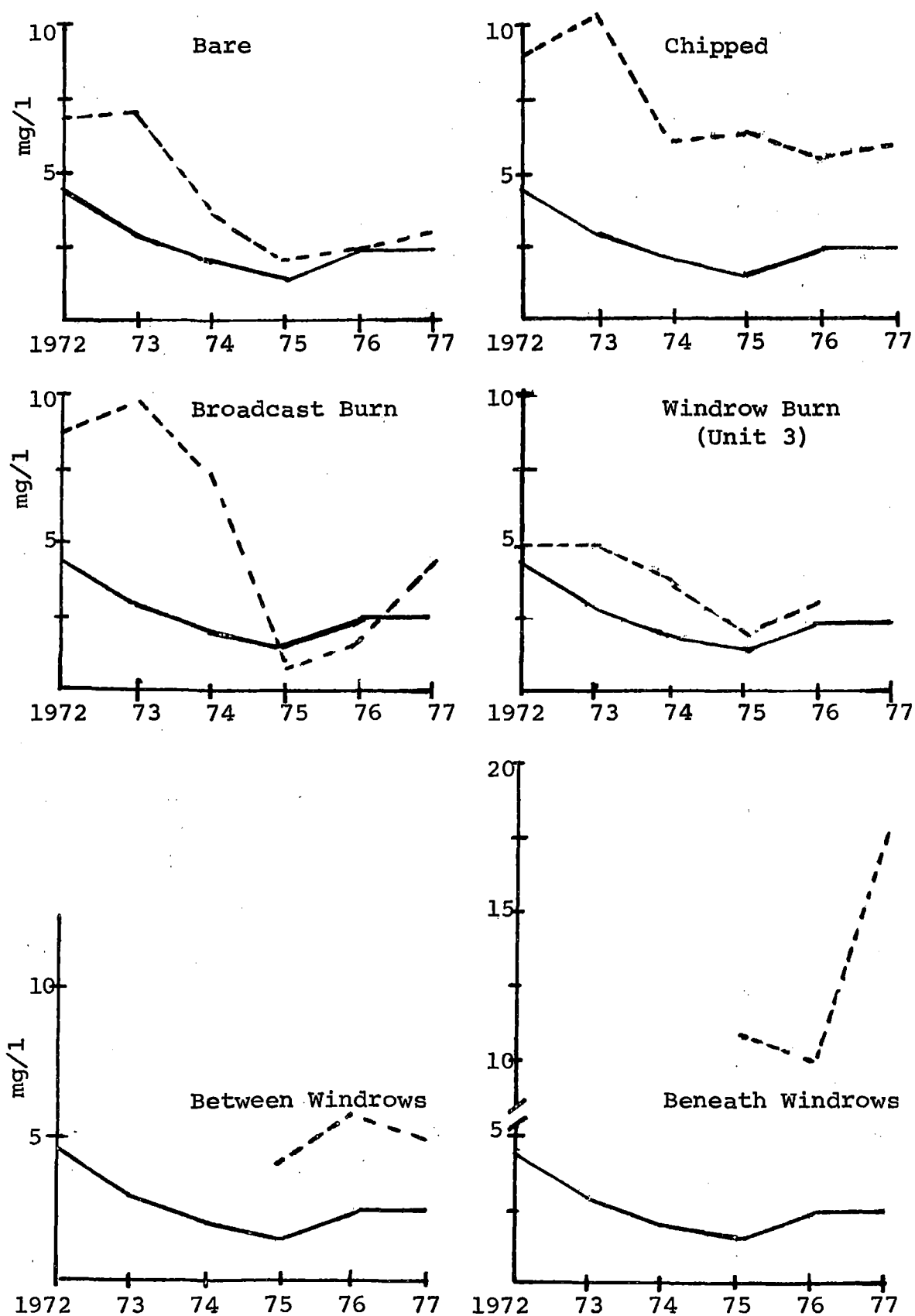


Figure 12. Yearly mean calcium concentrations; control(solid line) vs. treatment(dashed line).

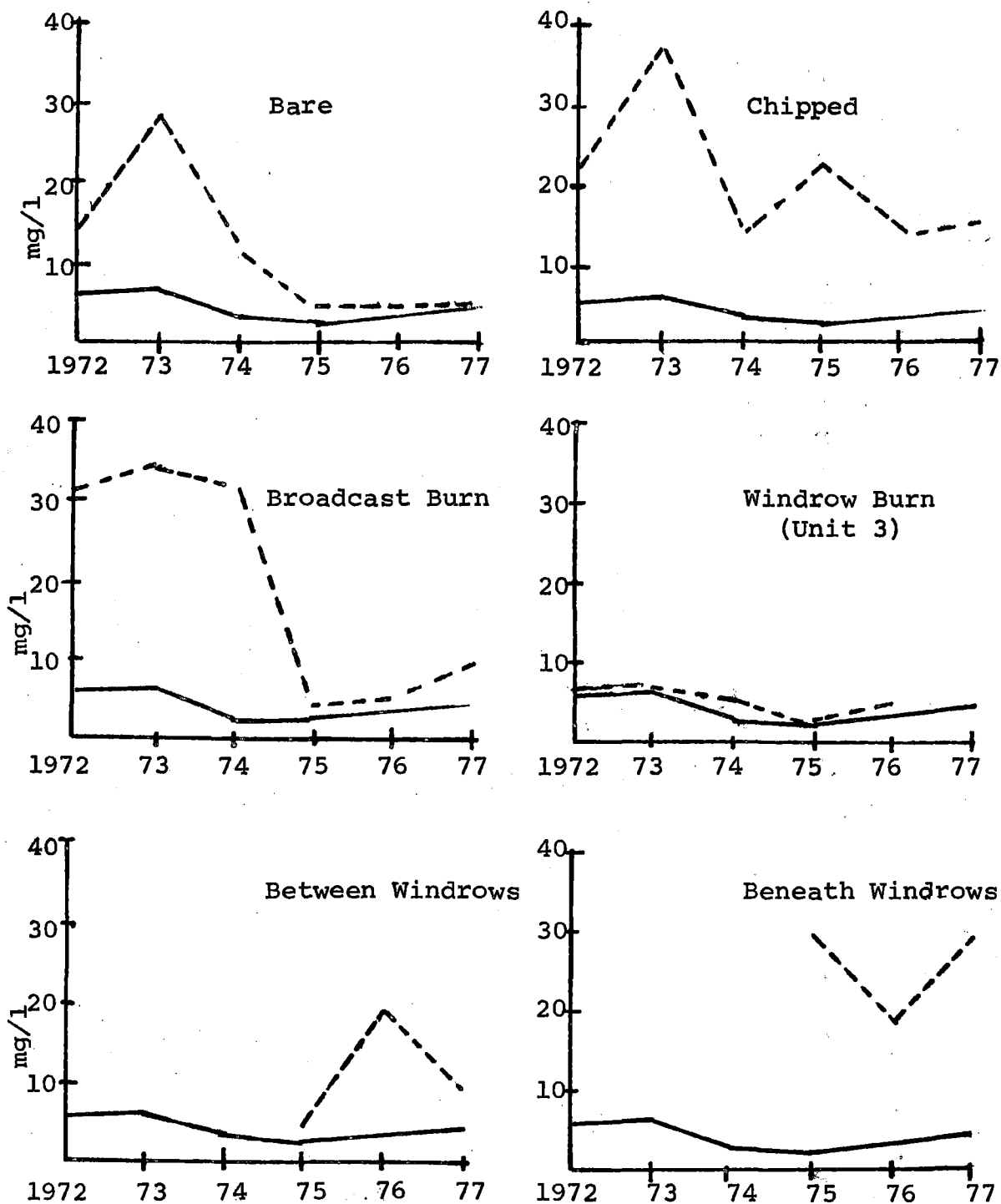


Figure 13. Maximum calcium concentrations; control(solid line) vs. treatment(dashed line).

Magnesium concentrations. Magnesium increases after treatments were similar to those of calcium (Figures 14 and 15). Elevated concentrations persisted on the chipped site, where maximum levels observed after application of chips were consistently two to five times greater than the levels observed in the control site. Immediately following treatment, maximum samples from the chipped site were as high as 10 mg/l, compared to a maximum of 1.9 mg/l in the forest control site. Increases in magnesium were also noted in the initial flush of nutrients after broadcast burning, where maximum levels as high as 8 mg/l were observed. The bare sites also produced a maximum value as high as 6.8 mg/l. Samples from the control site were never greater than 2 mg/l throughout the study. Only the chipped sites showed persistently elevated (although decreasing) levels throughout the entire sampling period. The windrow burn site (Unit 3) showed no increase over the control site.

The Unit 5 sites also showed relatively consistent response as levels increased up to 12 mg/l (12 times greater than the control) underneath the windrows while increasing only slightly between the windrows.

Nitrate-nitrogen concentrations. All treatments showed substantial increases of nitrate-nitrogen after clearcutting. Maximum concentrations as high as 12 mg/l were observed in 1977 in the broadcast burn site. As seen in Figure 16 and 17, the elevated levels actually have increased throughout the sampling period.

Particularly high levels of nitrate-nitrogen have been observed underneath the windrows in Unit 5. Maximum values greater than

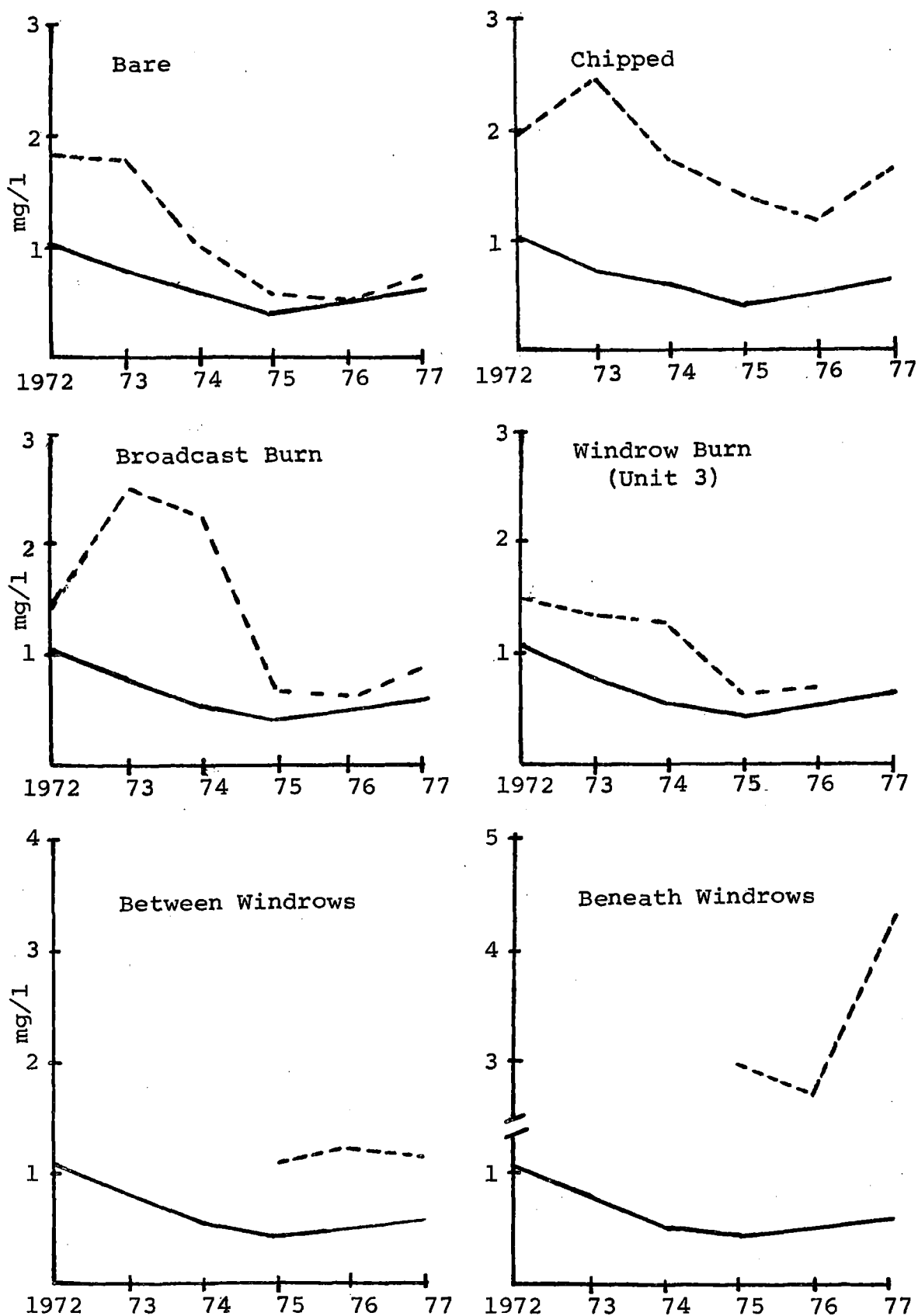


Figure 14. Yearly mean magnesium concentrations; control(solid line) vs. treatment(dashed line).



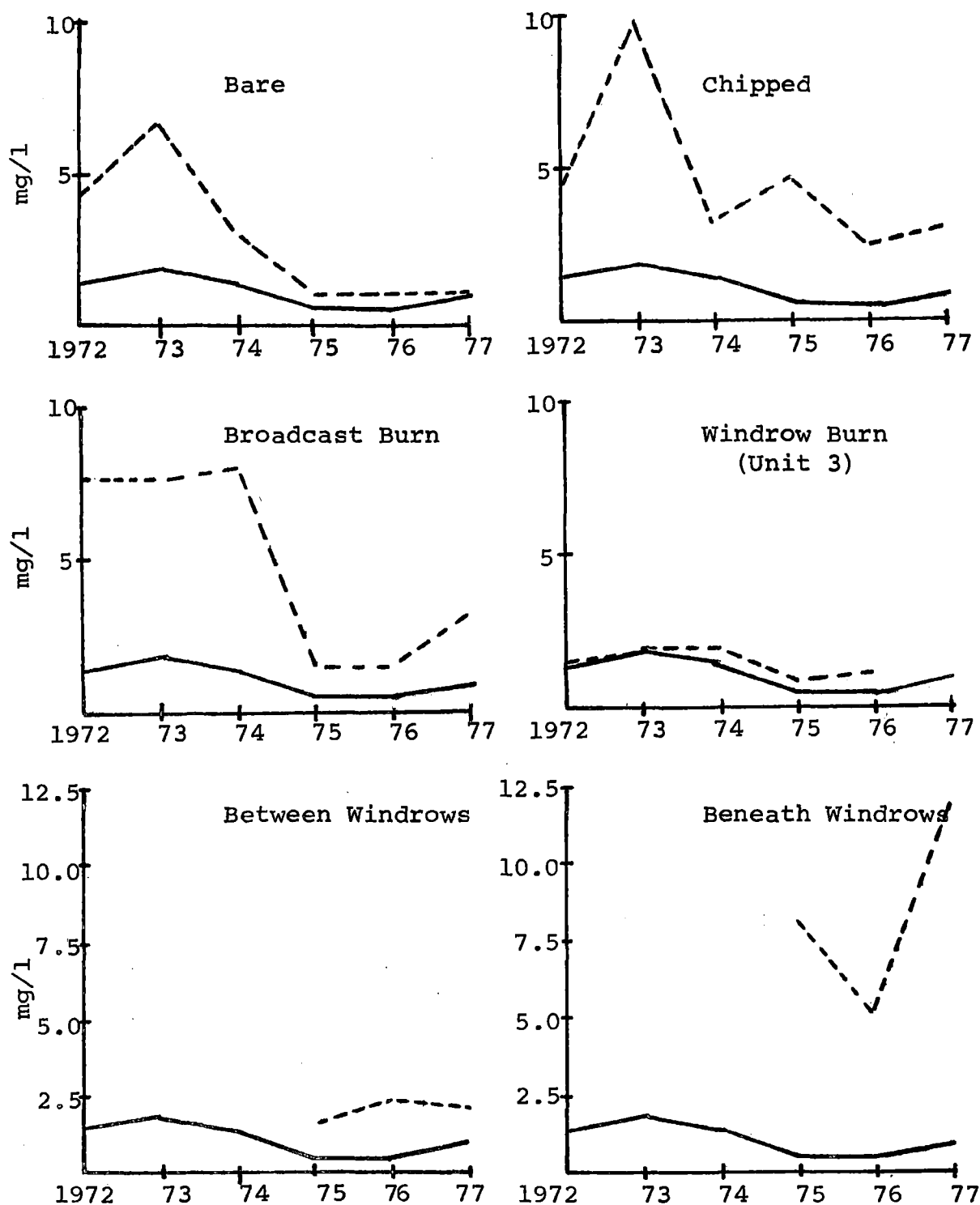


Figure 15. Maximum Magnesium Concentrations; Control(solid line) vs. treatment(dashed line).

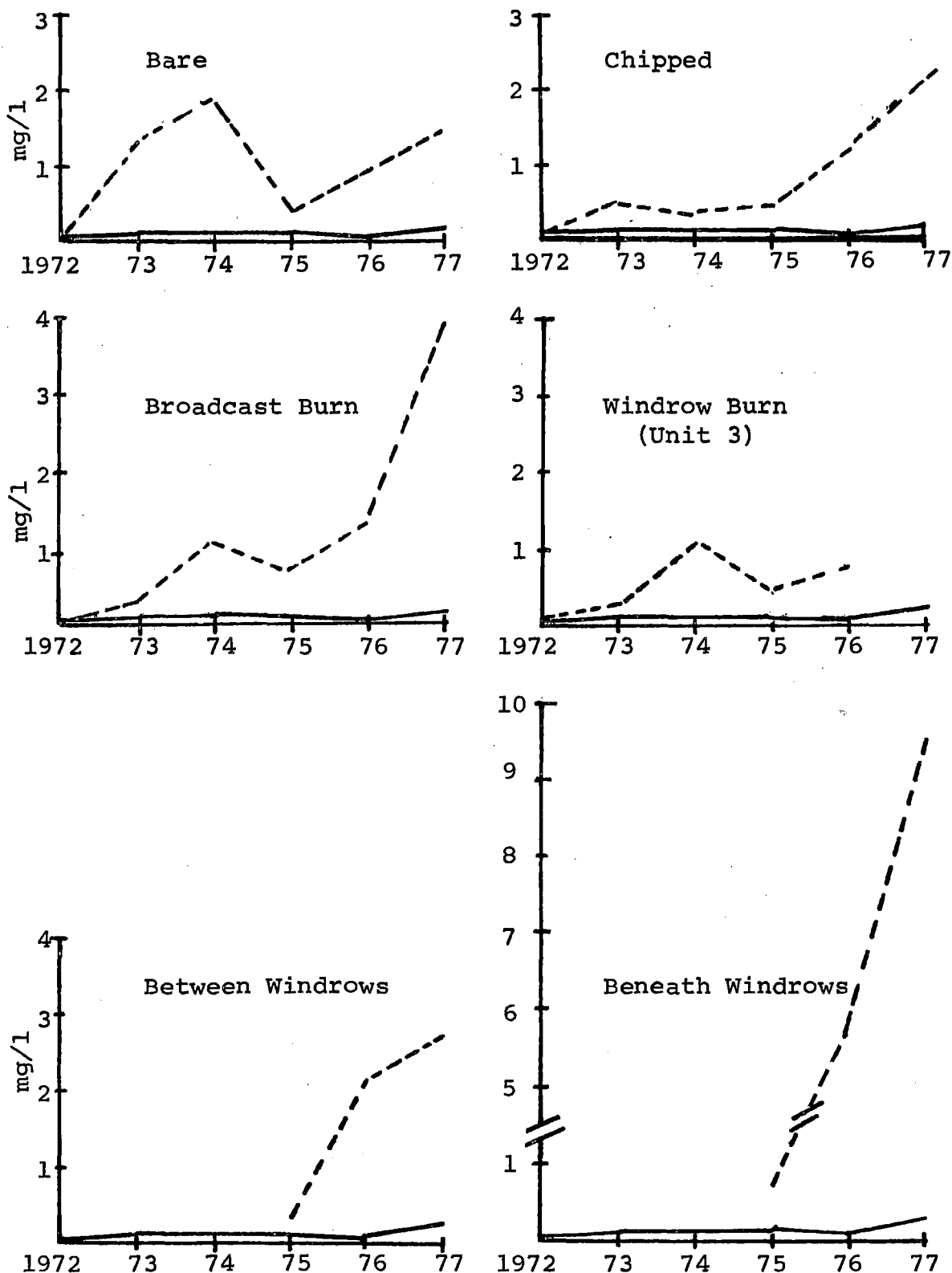


Figure 16. Yearly mean nitrate-nitrogen concentrations; control(solid line) vs. treatment(dashed line).

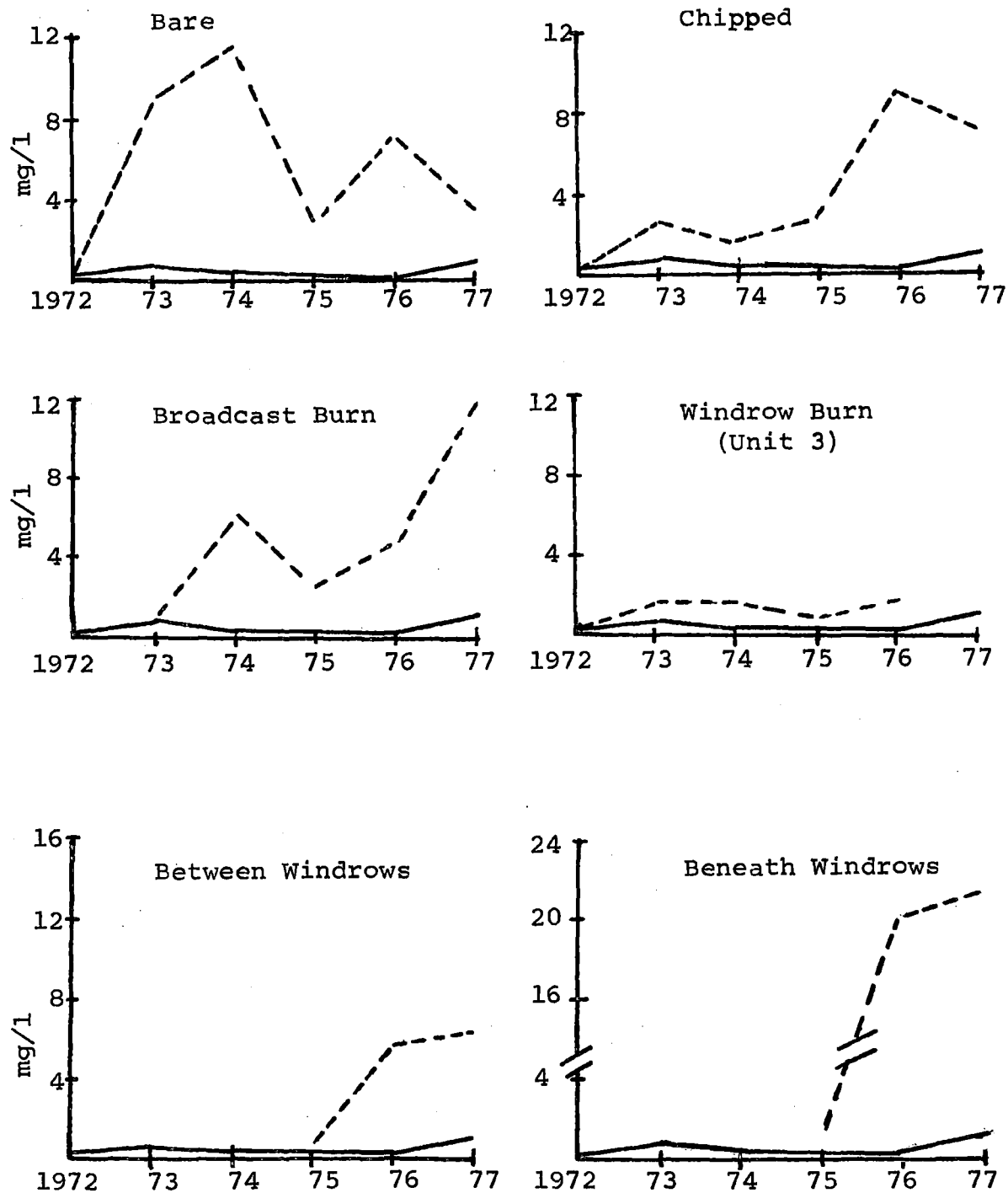


Figure 17. Maximum nitrate-nitrogen concentrations; control (solid line) vs. treatment (dashed line).

20 mg/l were observed in the 2 years following treatment. In Unit 5, the burn was quite intense and no revegetation has been observed under the windrows.

Some levels observed were above the drinking water limit of 10 mg/l  $\text{NO}_3\text{-N}$  (Environmental Protection Agency 1972). However, dilution from runoff from untreated areas usually will mitigate this potential problem.

Phenol concentrations. Increased phenols were noted in two of the treatment sites. After chips were spread, phenol levels were as high as 1,450 ug/l and on the bare sites maximum concentrations reached as high as 780 ug/l. This is most likely due to two processes. In the chipped areas, the amount of surface area per unit volume of slash had been greatly increased, making available much more organic material to the leaching process. In the bare areas, some of the organic matter incorporated into surface horizons by mechanical clearing and skidding may have contributed to the increase in available organic matter for leaching. This elevation in phenols rapidly diminished within 2 years after treatment (Figure 18).

On the other hand, areas which were burned did not show appreciable increases after treatment. This was probably due to the rapid volatilization of much of the organics during the combustion process. This seems to hold true for all burn treatments, including Unit 5.

Phenols are toxic at concentrations far below those observed in the chipped sites. Due to possible carcinogenic properties when chlorinated and odor problems, drinking water should contain no

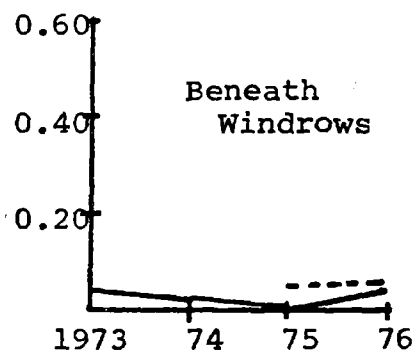
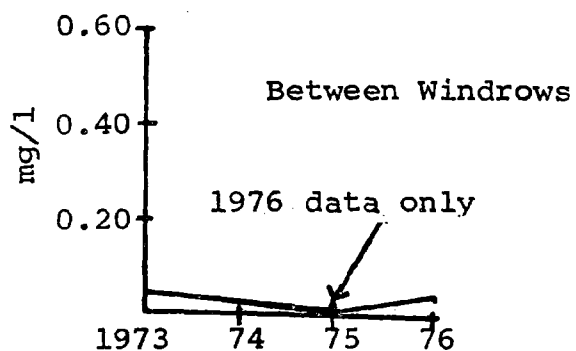
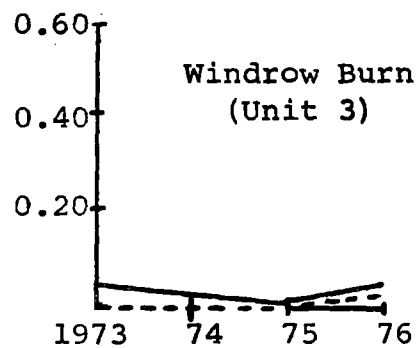
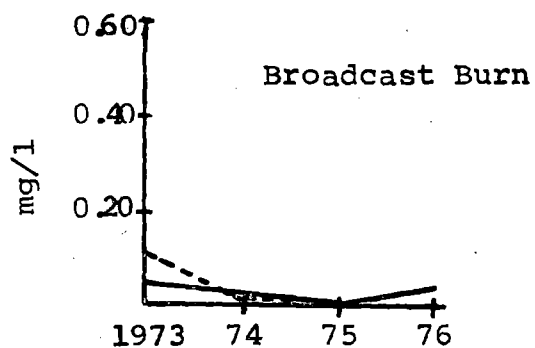
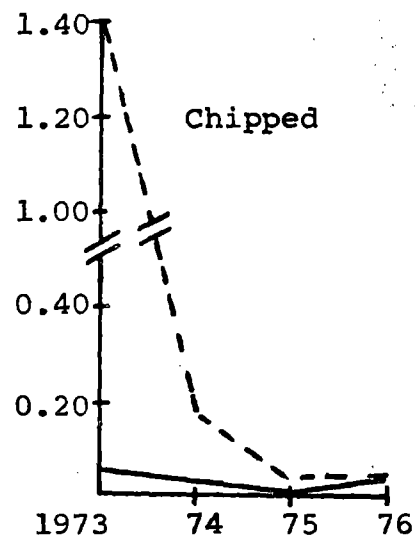
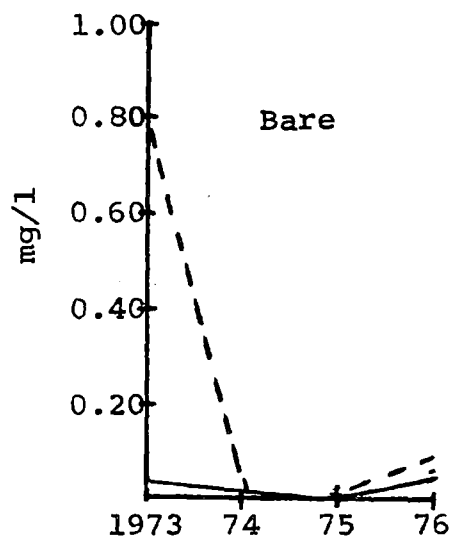


Figure 18. Maximum total phenol concentrations; control (solid line) vs. treatment (dashed line).

more than 1 ug/l (EPA 1972). In the wildland environment, levels as low as 100 ug/l show signs of toxicity to fish (State of California 1963). Reduced vigor and poor survival of seedlings planted beneath the wood chips at the study area were also observed (Schmidt 1978, pers. comm.).

Electrical conductivity. Electrical conductivity is a good relative indicator of total dissolved ionic species in solution. Considering the linear relationship between electrical conductivity (EC) and ionic total dissolved solids (TDS), comparison of EC between treatment and control sites will, in general, help in evaluating the intensity and persistence of ionic increases in soil solution as a result of the various treatments.

Specifically the burned sites showed the most dramatic increases over the control site, with EC as high as 536 umhos/cm in the broadcast burn (Figures 19 and 20). However, these greatly increased levels were seen to rapidly diminish within 2 to 3 years after treatment, with the exception of the chipped site, which remained slightly elevated through the study.

Using the general relationship  $TDS (mg/l) = EC(umhos/cm) \times 0.65$ , the data clearly showed that a major portion of the ionic species in the sample solution were not accounted for. Possible explanation of this could be the presence of dissolved carbonate species, particularly  $HCO_3^-$ , as well as Fe, Zn and ionic organics which were not measured.

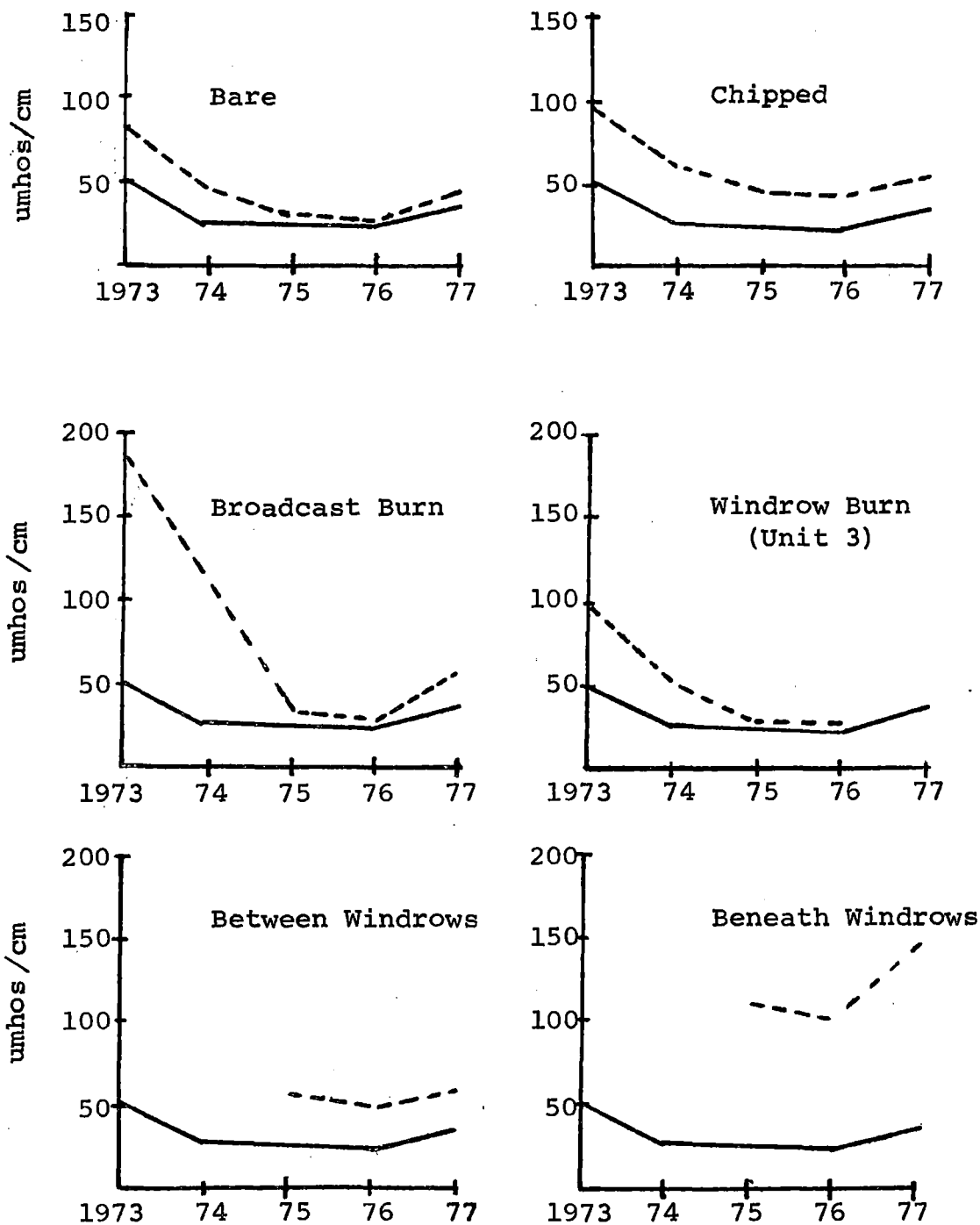


Figure 19. Yearly mean specific conductance levels; control(solid line) vs. treatment(dashed line).

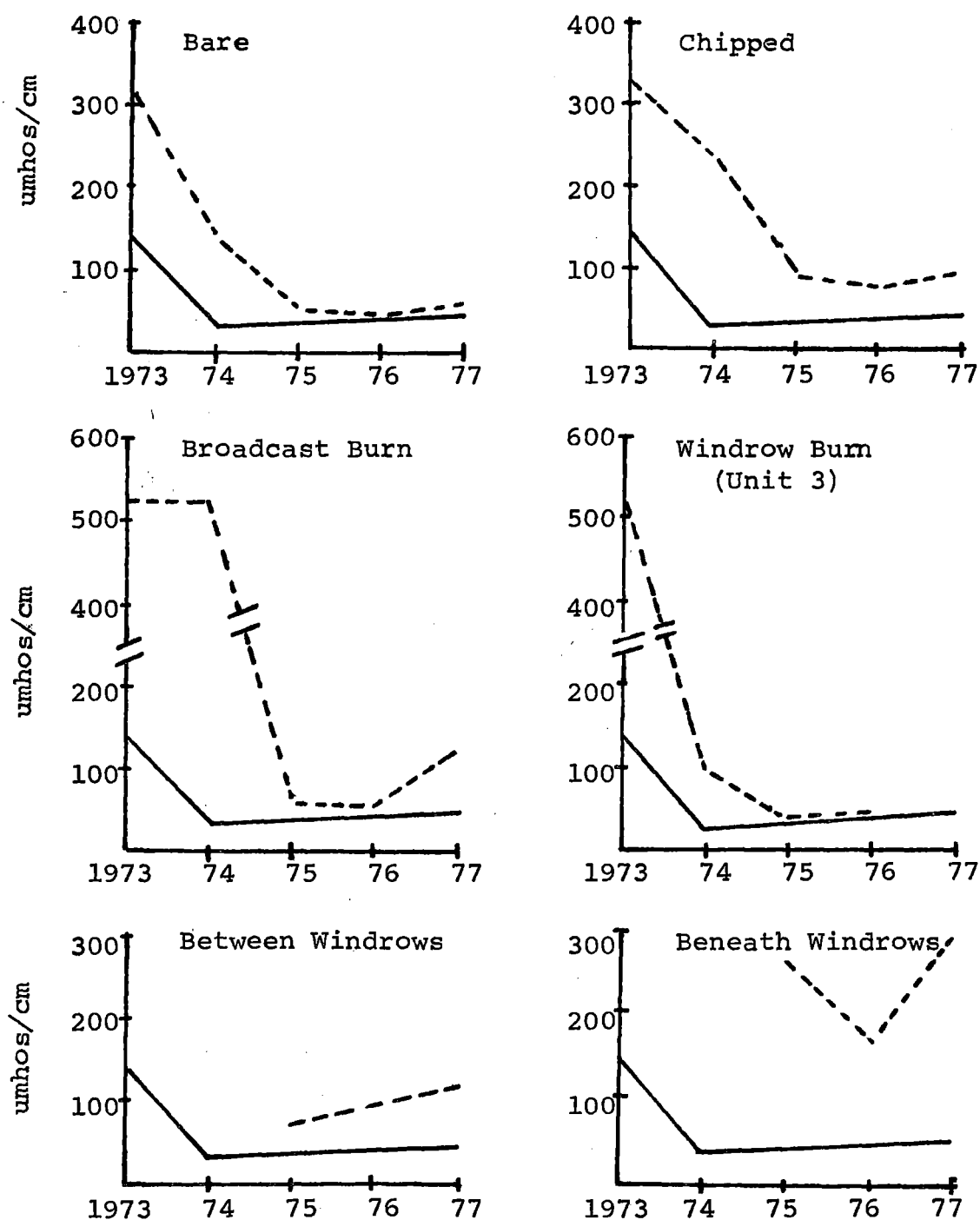


Figure 20. Maximum specific conductance levels; control (solid line) vs. treatment (dashed line).



## DISCUSSION AND CONCLUSIONS

### Alternatives to Burning

Bare sites. Increases were noted in all chemical parameters measured. Of major importance is the increase of nitrates which attained maximum values from 3 to 37 times over the forest site. This increase in nitrate may be due to several causes. The bare sites contained significant amounts of residue after treatment in 1972. Decay of this organic matter continued throughout the study. Organisms convert organic nitrogen to ammonia, and then further to nitrates and nitrites. The important end products of this series of reactions are hydrogen ions and nitrate ions. With a lowered pH, the major cations become more soluble and available for transport (Likens et al. 1969). The hydrogen ions selectively replace the cations on the exchange matrix and free them to leaching processes. Biochemical activity has been slow, primarily due to a climate which restricts microbial activity. Also, with the removal of timber came the influx of legumes, and other nitrogen fixers; all which contributed to nitrogen levels in the soil-water system.

The presence of organic matter, increases in soil moisture, elevated surface temperatures (DeByle 1975, pers. comm.), and the presence of loam and sandy loam soils, all contribute to the losses of nutrients from the bare sites. Conditions at the Union Pass area were somewhat similar to conditions found in the Hubbard Brook experiments mentioned earlier. Often maximum increases in nutrient concentrations in soil-water on the bare sites were in the same

order of magnitude as maximum concentrations observed in streamwater at Hubbard Brook. For example, at Hubbard Brook nitrate-nitrogen increased from less than 0.1 mg/l to 18.0 mg/l. At one point, in the bare sites on the Union Pass study, nitrates were as high as 11.4 mg/l. Forest control sites remained below 1 mg/l at all times. It should be noted that yearly mean concentrations in the bare sites never exceeded 2.0 mg/l. It would be improper to try to compare the increases found in streamflow with the maximum values observed in the soil-water at Union Pass, as dilution effects and variability throughout the site are not considered, as well as totally different sources of samples and dissimilar sampling techniques. But apparently similar nitrification processes were taking place at the Union Pass study as were seen at Hubbard Brook.

In addition to the increase of nitrate anions, the concentrations of four major cations increased under the bare condition. Calcium, which represents the major inorganic cation in woody materials, showed the greatest absolute increase and was increased five times over the forest control site, from 6 mg/l to 30 mg/l. Maximum concentrations of magnesium increased approximately three-fold.

In general, the bare treatment had a minimal effect on subsurface inorganic water quality. None of the cations and anions measured (with the possible exception of nitrates) showed any potentially hazardous concentrations throughout the study period, and effects of treatment, if any, diminished within 2 to 3 years after treatment.

However, phenols became highly elevated (up to 780 ug/l) in the 2 years following treatment. The phenol level the first few

years after treatment may be due to fine organic debris remaining onsite and incorporated into the soil during the clearing of the site by heavy machinery. This increased organic matter, as well as increased soil moisture due to reduced evapotranspiration after cutting, would promote rapid increases of soluble organics in the soil-water system. However, high levels of phenols only persisted through the 2 years following treatment.

Chipped sites. With the exception of sodium, all parameters showed a persistent increase in the areas where chips were spread. Concentrations of calcium, magnesium, potassium and nitrate increased two or more times after treatment. Although the increases occurred within the first 2 years after treatment, concentrations of most ions remained elevated throughout the 6 year study.

An extensive discussion of the chemical composition and the rates of decomposition of lodgepole pine chipped material in Colorado was given by Carrier (1974). Carrier summarizes the chemical properties of chips and recognizes three categories of leachable material:

<u>Source</u>	<u>Percent of soluble species in leachate</u>
phenolics	50
carbohydrates	35
salts	15

Both the carbohydrates and phenolics represent potential sources of increased BOD when they enter a stream.

Decomposition of the chips is a function of physical, chemical, and biological interactions, as well as the wood type. Rates are usually dependent on temperature and moisture. Currier's (1974) results of a laboratory simulation of chip decomposition and resultant soil-water concentration centered around phenolics. He reports that concentrations rose as high as 8.0 mg/l total phenols in distilled water passed through a soil core which previously had leachate solution applied to it. However, the phenolic concentration decreased 50 percent with depth. Currier concluded that most phenolics decomposed and/or became bound to the soil particles. In the Union Pass study, the phenol concentrations rose as high as 1.450 mg/l under the chipped material. The phenol levels in the chipped sites rapidly decreased in concentration within 3 years of treatment.

Examination of the site at the end of the study showed that most of the chipped material is still in much the original form it was in immediately following treatment. Very little physical decomposition was evident. Therefore, it can be expected that concentrations of the major cations and anions in less soluble form will continue to remain elevated throughout the slow decomposition of the chips. Since virtually no regeneration or return of any cover has appeared on these sites, nitrogen concentrations in soil-water solution will remain high until the area becomes revegetated.

### Burning of Slash

Broadcast burn. Major increases in ionic concentrations were noted in the soil-water following burning. Maximum concentrations

of potassium, calcium, magnesium and nitrate-nitrogen were at least five times greater on the broadcast burn sites than on the control. Burning of the residue will accelerate the solubility of elements by converting the residue to ash and increasing its susceptibility to leaching. This treatment, however, exhibited only transitory effects and most elements approached control levels within 3 years after burning.

Many chemical trends noted in the Union Pass study under broadcast burning resembled results observed in an earlier study on the H. J. Andrews Experimental Forest in the Oregon Cascades (Fredriksen 1971). For example, calcium levels observed in streamflow in the Oregon study increased from 4.1 mg/l to a maximum of 31.0 mg/l after burning. Similarly, in the Union Pass study, maximum levels under broadcast burn sites in soil-water reached 34.6 mg/l. Nearly identical increases in magnesium concentrations occurred in both studies as well. Changes in maximum concentrations of nutrients in both studies are compared in Table 4.

In another study of chemical constituents in overland flow draining broadcast burn plots at Newman Ridge, Montana (DeByle and Packer 1972), concentrations of nutrients in the overland flow were higher following burning. Potassium was at least one order of magnitude higher in concentration (after treatment) than observed in the H. J. Andrews and Union Pass studies. Probably this was due to the lack of interaction with the exchange sites in the soil matrix.

Table 4. Maximum concentrations in mg/l in streamwater, soil-water, and overland flow following clearcutting and broadcast burning in the H. J. Andrews, Union Pass, and Newman Ridge studies.

Nutrient	H. J. Andrews		Union Pass		Newman Ridge	
	Streamwater		Soil-water		Overland flow	
	Broadcast burn	Control	Broadcast burn	Control	Broadcast burn	Control
Ca	31.0	4.1	34.6	6.5	14.0	7.0
Mg	10.8	1.3	8.0	1.9	9.5	0.6
K	4.4	0.5	17.3	4.3	58.0	10.0
Na	6.7	3.0	7.3	5.0	-	-
NO <sub>3</sub> -N	0.6	0.01	11.7	0.9	-	-

In both the Union Pass and H. J. Andrews studies water sampled had percolated through the soil system or thus been diluted by other water sources.

In all studies, effects of broadcast burning became negligible after only a few years. Most impact occurred from the rapid initial flush of nutrients released by the ash layer following burning.

As opposed to the chipped or bare treatments, phenol levels in the burned sites did not show dramatic increases after treatment. This was due, in part, to the rapid volatilization of much of the organics during the burn, as well as limited activity of heavy equipment on the site which could have contributed to the incorporation of organic debris in the upper soil horizon.

Windrow burn (Unit 3). This site showed minimal, if any, change from the control site for virtually all chemical parameters monitored. This was possibly due to nonrepresentative placement of sampling tubes. Because of shallow soils near a ridge, only three tubes were located in this site and were placed next to, and not beneath the piles. Soils were shallower, less vegetation originally occupied the site, and clearcutting was not as dramatic an alteration to the site as occurred on other sites. The limited sampling in this treatment precludes any meaningful interpretation of the data.

Windrow burn (Unit 5). The windrows in Unit 5 were burned in 1974 and the intensity of the burn and resultant ash layer were considerably greater than windrow burn site in Unit 3. An ash layer remained beneath the windrows through 1977 and no signs of revegetation existed under any of the windrow sites. Considering the higher

intensity of the Unit 5 burn, the elevated levels of ions, especially potassium, calcium, magnesium, and nitrate-nitrogen are in agreement with data from the broadcast burn area. But, apparently the higher intensity burn and heavier ash layer resulted in correspondingly higher concentrations. In particular, nitrate-nitrogen was as high as 21 mg/l, and these extremes occurred in the first and second year after treatment. In general, the impact of the high intensity burn seems to be persisting longer than the cooler burns, although the data collected cover only 2 years after treatment.

Between the windrows in Unit 5 only moderate increases in ionic species occurred after treatment and no increases were noted in phenols. As is the case with the data from underneath the windrows, only 2 years of data are currently available, but the data suggest little possible impairment to water quality.



## IMPLICATIONS FOR LAND MANAGEMENT

The choice of a method for slash treatment can not be based solely on impact to the soil-water system. The results of this experiment must be evaluated in conjunction with parallel research investigating regeneration rates, alterations in soil structure, aesthetics, and impacts on wildlife habitat. In this framework the following is a summary of the major effects on soil-water chemistry of each of the treatments evaluated in this study, as well as recommendations for land management which can be concluded from the results.

In choosing the best method, one should consider what constitutes the best post-treatment conditions. In the context of water quality, one would look for a treatment which offers the least chemical alteration to the soil-water system, as well as the shortest duration between the impact of treatment and a return to pre-treatment conditions.

The bare treatment was characterized by the removal of most of the slash and treatment of residues offsite. With the removal of much of the slash from the site, changes in soil-water chemistry were primarily due to clearcutting, combined with the breakdown of the remaining residue.

As discussed earlier, these changes in soil-water chemistry were measurable and suggest that the changes noted in other treatments were, in actuality, composite effects of clearcutting plus the effects of the selected ways of accelerating slash breakdown by chipping or burning.

Considering that the bare treatment essentially represents the impact of clearcutting alone, a viable interpretation would be to evaluate the impact of the other slash disposal treatments as they compare with the bare conditions. The bare treatment produced increases in calcium to levels as high as 30 mg/l. Similar increases were noted in all other treatments except the windrow burn in Unit 3, which was not representative of the treatment. However, the elevated concentrations only lasted for 4 years following clearcutting in the bare and broadcast burn treatments, whereas in the chipped treatment, the concentrations continued to remain above control levels throughout the 6 years of the study. Also the concentrations beneath the windrows in Unit 5 appeared to be remaining considerably above the control site through the 3 years following clearcutting and windrow burning. Magnesium closely followed the behavior of calcium. The extent and duration of impacts of the treatments on potassium concentrations were also similar. Sodium was the only cation showing no important increase.

When evaluating the variation in phenol concentrations between the treatments, the conclusion is quite simple: In treatments which allow the residue to remain onsite (chipped) or a large amount of debris remains untreated (bare sites), phenol concentrations will increase; when slash has been burned (broadcast burn and windrow burn), no increase in phenols is noted.

Nitrates have remained at levels exceeding the concentrations found at the control site in all treatments (excluding Unit 3).

Often nitrate-nitrogen concentrations exceeded drinking water standards. Whether this represents a health hazard is a function of dilution, proximity to human consumption and length of persistence. Since no streamflow measurements were made on streams directly fed by the experimental sites, no conclusions can be made as to the extent of impact on water leaving the site. As such, nitrate-nitrogen concentrations do not appear to be a valid criteria for selecting an optimum treatment.

This summary of changes in soil-water chemistry following slash disposal leads to a direct conclusion: The bare treatment allows elevated levels of phenols to persist after cutting, possibly posing a problem to regeneration and water quality. The chipped treatment also causes increased phenols, again being a potential concern. Also, the chipping treatment results in the longest duration of altered soil-water chemistry. The windrow burn (Unit 5) may change the soil-water chemistry the greatest, but only immediately underneath the windrows. Although only 3 years of data have been collected, the data do not appear to show a rapid trend towards control levels. Broadcast burning demonstrates the most diffuse impact, with all parameters (excluding  $\text{NO}_3\text{-N}$ ) returning to control levels within 4 years after clearcutting. Also, no increases in phenols were noted.

Therefore, broadcast burning offers the least impact to soil-water chemistry of all treatments tested, and should be considered the best method of slash disposal.

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## APPENDIX

Table 5. Soil pedon description, forest control site, by Dr. A. R. Southard. 5% slope, north aspect.

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0 - 3"	Very dark grayish brown (10YR 3/2) loam; weak fine platy; nonsticky slightly plastic; many roots; clear wavy boundary.
3 - 7"	Dark brown (10YR 3/3) loam; weak fine platy; nonsticky slightly plastic; many roots; clear wavy boundary.
7 - 14"	Dark yellowish brown (10YR 4/4) loam; weak medium subangular blocky; nonsticky nonplastic; many roots; clear wavy boundary.
22 - 32"	Dark grayish brown (2.5Y 4/2) sandy loam; weak fine platy; nonsticky nonplastic; few roots; clear wavy boundary.
32 - 43"	Dark grayish brown (2.5Y 4/2) loam; weak fine platy; nonsticky slightly nonplastic; few faint mottles; gradual boundary.
43 - 60"	Dark grayish brown (2.5Y 4.2) loam; strong fine platy; slightly sticky slightly plastic; compact in places; a few mottles in a matrix of unoxidized glacial till. 25% coarse fragments.

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NOTE: Roots extend to 43 inches, few stones above 43 inch depth. Soil moist to 14 inches.

## UTAH STATE UNIVERSITY

Soils Laboratory

Logan, Utah

## SOIL ANALYSIS REPORT

COLLECTED BY Dr. A. R. Southard

DATE 1/9/73

LOCATION TETON Forest

LABORATORY NUMBER	COLLECTOR'S NUMBER	DEPTH IN INCHES	HORIZON	PARTICLE SIZE DISTRIBUTION (in mm.) (percent)										Z	TEXTURAL CLASS	Total Sand
				VERY COARSE SAND 3-1	COARSE SAND 1-0.5	MEDIUM SAND 0.5-0.25	FINE SAND 0.25-0.10	VERY FINE SAND 0.10-0.05	SILT 0.05-0.002	CLAY <0.002		0.02-0.002	> 2 mm.			
72-2690	F	0-3		organic	matter									18.9		
2691		3-7		10.5	9.5	5.7	11.9	4.9						23.8		47.5
2692		7-14		9.0	8.9	5.6	13.1	12.4						24.7		49.0
2693		14-22		7.8	8.0	5.7	15.2	15.0						22.7		51.7
2694		22-32		11.1	11.0	7.0	15.1	13.3						27.1		57.5
2695		32-43		8.7	12.0	8.2	16.7	12.6						28.1		58.2
2696		43-60		8.4	11.8	8.5	17.3	12.8						32.0		58.8
				pH				ELECTRICAL CONDUCTIVITY				NaHCO <sub>3</sub>		MOISTURE TENSIONS		
				SATURATED PASTE	ORGANIC MATTER %	ORGANIC CARBON %	Nitrate NITROGEN ppm	Fe ppm	Zn ppm	EC x 10 <sup>3</sup> MILLIMHOS PER CM @ 25°C		K ppm	P ppm	1/3 ATMOS. %	15 ATMOS. %	
72-2690				5.7		2.6	.1	148	1.7	.3		285	38	18.6	8.0	
2691				5.6		1.2	.4	144	1.3	<.2		135	54	17.3	7.1	
2692				5.5		.5	.4	144	1.4	<.2		77	39	14.7	6.9	
2693				5.2		.3		80	1.7	<.2		98	22	12.3	6.0	
2694				5.2		.3		72	1.2	<.2		135	15	12.6	5.2	
2695				5.2		.2	.2	39	1.4	<.2		120	9.3	13.6	6.4	
2696				5.7		.1	.2	28	1.3	<.2		90	8.3	13.7	6.3	
				Extractable CATIONS				EXCHANGEABLE SODIUM PERCENTAGE ESP				SATURATION EXTRACT SOLUBLE				PERCENT MOISTURE AT SATURATION
				CATION EXCHANGE CAPACITY	Ca	Mg	Na	K		Na	K	Ca	Mg			
					milliequivalents per 100 g soil					milliequivalents per 100 g						
72-2690						.89	.72		.01	.02	.05	.02				42
2691						<.20	.37		.01	<.01	.02	.01				32
2692						<.20	.17		.01	<.01	.01	.01				29
2693						<.20	.22		.01	<.01	.01	<.01				24
2694						<.20	.30		.01	<.01	.01	<.01				21
2695						<.20	.26		.01	<.01	.01	<.01				22
2696						<.20	.18		.01	<.01	.01	<.01				23



Table 6. Soil pedon description, bare site (Unit 1), by Dr. A. R. Southard. 12% slope, northwest aspect.

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1/2 - 0"	Organic layer.
0 - 6"	Very dark grayish brown (10YR 3/2) loam; weak coarse platy; sticky and slightly plastic; many roots; clear wavy boundary.
6 - 17"	Dark yellowish brown (10YR 4/4) loam; moderate medium subangular blocks; sticky and slightly plastic; many roots; clear wavy boundary.
17 - 30"	Yellowish brown (10YR 5/4) gravelly heavy loam; weak fine platy; sticky and plastic; few roots; gradual boundary.
30 - 50"	Yellowish brown (10YR 4/4) gravelly clay loam; weak fine platy; sticky and plastic; few roots; gradual boundary.
50 - 65"	Dark yellowish brown (10YR 4/4) gravelly clay loam; weak fine platy; sticky and plastic.

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NOTE: Roots to 50 inches, coarse fragments below 17 inches, more than 50 percent by volume, soil moist to 24 inches.

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LABORATORY NUMBER	COLLECTOR'S NUMBER	DEPTH IN INCHES	HORIZON	PARTICLE SIZE DISTRIBUTION (in mm.) (percent)										TEXTURAL CLASS	Total Sand
				VERY COARSE SAND 2-1	COARSE SAND 1-0.5	MEDIUM SAND 0.5-0.25	FINE SAND 0.25-0.10	VERY FINE SAND 0.10-0.05	SILT 0.05-0.002	CLAY <0.002			X > 2 mm.		
72-2726	1-HC	0-6		organic matter										13.6	
2727		6-17		9.8	8.6	5.1	11.8	16.2						23.3	49.5
2728		17-30		5.6	8.2	6.4	17.0	14.0						28.4	51.2
2729		30-50		6.1	8.4	6.8	17.0	12.5						43.3	50.8
2730		50-65		9.8	13.2	8.9	16.4	12.2						43.4	60.5
								ELECTRICAL CONDUCTIVITY 1:1 <sup>1/2</sup> MULLINBROS PER CM @ 25°C		NAHCO <sub>3</sub>		MOISTURE TENSIONS			
				pH SATURATED PASTE	ORGANIC MATTER %	ORGANIC CARBON %	Nitrate NITROGEN ppm	Fe ppm	Zn ppm	K ppm	P ppm	1/2 ATMOS. %	15 ATMOS. %		
72-2726		5.6			1.9	.2	226	1.6	<.2	248	38	22.1	7.8		
2727		5.5			.3	<.1	129	1.1	<.2	150	26	16.9	6.4		
2728		5.1			.2	.1	71	1.1	<.2	135	14	17.3	8.3		
2729		5.2			.3	.1	42	1.1	<.2	113	15	17.3	8.2		
2730		5.5			.1	<.1	24	.9	<.2	90	12	13.5	5.8		
				Extractable CATIONS				SATURATION EXTRACT SOLUBLE							
				CATION EXCHANGE CAPACITY	Ca	Mg	Na	K	EXCHANGEABLE SODIUM PERCENTAGE ESP	Na	K	Ca	Mg		
				milliequivalents per 100g soil					milliequivalents per 100 g						
72-2726					<.20		.62		.01	.01	.02	.01		41	
2727					<.20		.33		.01	<.01	.01	<.01		29	
2728					<.20		.33		.01	<.01	.01	<.01		30	
2729					<.20		.28		.01	<.01	.01	<.01		30	
2730					<.20		.18		.01	<.01	.01	<.01		22	

Table 7. Soil pedon description, broadcast burn site (Unit 3), by Dr. A. R. Southard. 5% slope, northwest aspect.

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0 - 2"	Very dark grayish brown (10YR 3/2) loam; weak medium platy; nonsticky nonplastic; many roots; clearly wavy boundary.
2 - 8"	Dark brown (10YR 3/3) loam; moderate medium granular; slightly sticky slightly plastic; many roots; clear wavy boundary.
8 - 16"	Dark yellowish brown (10YR 4/4) silt loam; moderate medium granular; slightly sticky slightly plastic; many roots; gradual boundary.
16 - 28"	Yellowish brown (10YR 5/4) loam; weak medium subgranular blocky; nonsticky slightly plastic; few roots; gradual boundary. Material coarser than 2 mm 35%.
28 - 40"	Yellowish brown (10YR 5/4) loam; weak fine subangular blocky; slightly sticky slightly plastic; few roots; gradual boundary. Material coarser than 2 mm 35%.
40 - 52"	Yellowish brown (10YR 5/4) loam; massive; nonstocky nonplastic; gradual boundary.
52 - 66"	Yellowish brown (10YR 5/4) loam; massive; nonsticky nonplastic. Material coarser than 2 mm 60%.

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LABORATORY NUMBER	COLLECTOR'S NUMBER	DEPTH IN INCHES	HORIZON	PARTICLE SIZE DISTRIBUTION (in mm.) (percent)										Z	TEXTURAL CLASS	Total Sand
				VERY COARSE SAND	COARSE SAND	MEDIUM SAND	FINE SAND	VERY FINE SAND	SILT	CLAY						
				2-4	4-6.5	0.5-0.75	0.25-0.10	0.10-0.05	0.05-0.002	<0.002	0.02-0.002	> 2 mm.				
72-2703	3-BB	0-2		organic matter										49.7		
2704		2-8		organic matter										51.0		
2705		8-16		6.0	5.9	8.4	21.9	10.8					59.0		53.0	
2706		16-28		5.1	5.8	10.8	29.0	10.2					53.5		60.9	
2707		28-40		5.1	7.0	9.2	29.0	11.6					60.2		61.9	
2708		40-52		2.5	5.0	9.7	34.0	12.1					68.0		63.3	
2709		52-66		2.4	4.4	10.3	32.2	11.7					65.0		61.0	
	pH SATURATED PASTE			ORGANIC MATTER %	ORGANIC CARBON %	Nitrate NITROGEN ppm	Fe ppm	Zn ppm	ELECTRICAL CONDUCTIVITY EC, 10 <sup>3</sup> MILLIMHOS PER CM @ 25°C		NaHCO <sub>3</sub>		MOISTURE TENSIONS			
											K ppm	P ppm	1/2 ATMOS. %	15 ATMOS. %		
72-2703	5.7			6.6	.2	225	7.7	.5			420	23	32.9	12.4		
2704	5.7			2.8	.2	232	1.9	.3			263	16	25.7	9.9		
2705	5.6			.3	.4	67	1.0	<.2			53	3.5	15.1	5.2		
2706	5.3			.2		45	1.1	<.2			83	2.3	12.5	4.8		
2707	5.2			.2		33	1.4	<.2			90	.8	11.7	5.0		
2708	5.2			.2	.2	27	1.4	<.2			60	1.	13.1	5.5		
2709	5.4			.1	.2	22	1.6	<.2			53	.9	14.6	5.7		
	CATION EXCHANGE CAPACITY	Extractable CATIONS				EXCHANGE-ABLE SODIUM PERCENT-AGE ESP	SATURATION EXTRACT SOLUBLE						PER CENT MOISTURE AT SATURATION			
		Ca	Mg	Na	K		Na	K	Ca	Mg						
		milliequivalents per 100g soil					milliequivalents per 100 g									
72-2703						<.20	.93	.02	.05	.11	.03				64	
2704						<.20	.60	.02	.01	.04	.01				50	
2705						<.20	.10	.01	<.01	<.01	<.01				24	
2706						<.20	.16	.01	<.01	<.01	<.01				20	
2707						<.20	.20	.01	<.01	.01	<.01				21	
2708						<.20	.11	.01	<.01	.01	<.01				24	
2709						<.20	.10	.01	<.01	.01	<.01				25	

Table 8. Soil pedon description, chipped site (Unit 4), by Dr. A. R. Southard. 18% slope, northwest aspect.

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0 - 1"	Organic layer.
0 - 5"	Very dark grayish brown (10YR 3/2) loam; weak coarse platy separating to moderate medium subangular blocky; nonsticky; slightly plastic; many roots; clear wavy boundary.
5 - 15"	Dark grayish brown (10YR 4/2) loam; moderate medium subangular blocky; nonsticky slightly plastic; few roots; clear wavy boundary.
15 - 26"	Dark grayish brown (2.5Y 4/2) sandy loam; moderate medium granular; nonsticky nonplastic; few roots; clear wavy boundary.
26 - 39"	Dark grayish brown (2.5Y 4/2) sandy loam; strong fine platy; nonsticky nonplastic; few roots; gradual boundary.
39 - 55"	Similar to above.
55 - 66"	Separated for analysis.

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				VERY COARSE SAND 3-1	COARSE SAND 1-0.5	MEDIUM SAND 0.5-0.25	FINE SAND 0.25-0.10	VERY FINE SAND 0.10-0.05	SILT 0.05-0.002	CLAY <0.002			% > 2mm.				
72-2697 2698 2699 2700 2701 2702	4-C	0-5 5-15 15-26 26-39 39-55 55-66			organic matter 13.5 13.8 12.8 9.2 10.6 10.8	13.8 16.7 15.5 15.5 16.2 16.7	8.1 10.3 10.4 10.4 10.5 10.7	13.8 17.9 19.7 19.7 19.1 18.8	9.1 11.0 12.8 12.4 12.4 11.7				37.2 34.7 25.3 29.7 42.8 34.0		58.3 68.7 67.6 68.8 68.7		
				Nitrate				ELECTRICAL CONDUCTIVITY EC x 10 <sup>3</sup> MILLIMHOS PER CM @ 25°C		NaHCO <sub>3</sub>		MOISTURE TENSIONS					
				pH SATURATED PASTE	ORGANIC MATTER %	ORGANIC CARBON %	NITROGEN ppm	Fe ppm	Zn ppm		K ppm	P ppm	1/2 ATMOS. %	15 ATMOS. %			
72-2697 2698 2699 2700 2701 2702		5.5 5.5 5.5 5.2 5.3 5.7			3.2 .6 .2 .2 .1 .1	.2 .3 .2  .2 .1	140 129 70 40 39 38	2.5 1.6 1.8 1.3 1.3 1.3	.3 <.2 .2 <.2 <.2 <.2		165 105 75 75 75 75	33 19 11 10 12 9.4	19.4 12.7 10.1 10.9 9.5 10.4	7.7 5.9 4.4 4.7 4.2 4.5			
				Extractable CATIONS				SATURATION EXTRACT SOLUBLE									
				CATION EXCHANGE CAPACITY	Ca	Mg	Na	K	EXCHANGEABLE SODIUM PERCENT-AGE ESP	Na	K	Ca	Mg		PER CENT MOISTURE AT SATURATION		
				milliequivalents per 100g soil								milliequivalents per 100 g					
72-2697 2698 2699 2700 2701 2702					<.20 <.20 <.20 <.20 <.20 <.20	.55 .25 .15 .15 .13 .12			.01 .02 .01 .01 .01 .01	.01 <.01 <.01 <.01 <.01 <.01	.04 .01 .01 .01 .01 .01	.01 <.01 <.01 <.01 <.01 <.01		33 23 18 19 18 18			

Table 9. Soil pedon description, bare site (Unit 4), by Dr. A. R. Southard. 18% slope, northwest aspect.

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0 - 3"	Organic mat.
0 - 6"	Very dark grayish brown (10YR 3/2) loam; weak coarse platy parting to moderate medium subangular blocky; nonsticky slightly plastic; many roots; clear wavy boundary.
6 - 11"	Dark yellowish brown (10YR 4/4) loam; weak medium subangular blocky; nonsticky slightly plastic; many roots; clear wavy boundary.
11 - 19"	Dark yellowish brown (10YR 4/4) heavy loam; weak medium subangular blocky; sticky and plastic; few roots; gradual boundary.
19 - 29"	Dark yellowish brown (10YR 4/4) heavy loam; weak fine platy; sticky and plastic; clear wavy boundary.
29 - 38"	Dark yellowish brown (10YR 4/4) sandy loam; weak fine platy; slightly sticky slightly plastic; few roots; clear wavy boundary.
38 - 53"	Dark grayish brown (10YR 4/2 2.5Y) sandy loam; weak fine platy; nonsticky plastic; few roots.
53"	Water table.

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LABORATORY NUMBER	COLLECTOR'S NUMBER	DEPTH IN INCHES	HORIZON	PARTICLE SIZE DISTRIBUTION (in mm.) (percent)										Z	TEXTURAL CLASS	Total Sand
				VERY COARSE SAND 2-1	COARSE SAND 1-0.5	MEDIUM SAND 0.5-0.25	FINE SAND 0.25-0.10	VERY FINE SAND 0.10-0.05	SILT 0.05-0.002	CLAY <0.002						
72-2731	4 NC	0-6		organic matter										26.2		
2732		6-11		13.6	11.7	6.4	12.3	10.6					31.1	54.6		
2733		11-19		10.2	12.4	8.0	16.2	10.7					30.0	57.5		
2734		19-29		10.7	13.0	8.1	15.9	10.8					33.9	58.5		
2735		29-38		17.0	17.5	8.9	14.2	8.9					34.2	66.5		
2736		38-53		9.5	14.6	10.4	19.1	11.9					38.7	65.5		
				pH	Nitrate					ELECTRICAL CONDUCTIVITY RC x 10 <sup>3</sup> MILLIMHOS PER CM @ 25°C	NaHCO <sub>3</sub>		MOISTURE TENSIONS			
				SATURATED PASTE	ORGANIC MATTER %	ORGANIC CARBON %	NITROGEN ppm	Fe ppm	Zn ppm		K ppm	P ppm	1/2 ATMOS. %	15 ATMOS. %		
72-2731				5.4		1.0	.2	246	4.3	.2		158	31	18.4	7.0	
2732				5.6		.5	.3	132	1.0	<.2		113	20	15.1	6.0	
2733				5.3		.3	.2	94	.9	<.2		83	9.0	14.1	6.1	
2734				5.0		.3		51	.4	<.2		83	7.6	15.0	6.3	
2735				5.1		.2	.2	45	.6	<.2		90	7.8	13.8	5.5	
2736				5.3		.2	.2	30	.4	<.2		60	6.3	11.6	4.9	
				CATION EXCHANGE CAPACITY	Extractable CATIONS				EXCHANGEABLE SODIUM PERCENTAGE ESP	SATURATION EXTRACT SOLUBLE					PER CENT MOISTURE AT SATURATION	
					Ca	Mg	Na	K		Na	K	Ca	Mg			
				milliequivalents per 100g soil				milliequivalents per 100 g								
72-2731					<.20	.38			.01	<.01	.02	.01		40		
2732					<.20	.26			.01	<.01	.01	<.01		29		
2733					<.20	.17			.01	<.01	.01	<.01		26		
2734					<.20	.17			.01	<.01	.01	<.01		23		
2735					<.20	.16			.01	<.01	.01	<.01		20		
2736					<.20	.11			.01	<.01	.01	<.01		20		



PART II  
EVALUATION OF CERAMIC CUPS FOR DETERMINING  
SOIL SOLUTION CHEMISTRY

## INTRODUCTION

Within the last 15 years, ceramic cup samplers have been used to withdraw soil water samples in a variety of field conditions. Some of the current ways in which ceramic cups are being used in research and management include sampling groundwater, sewage drainages, mining spoils, and irrigation water supplies.

Since 1970, investigations into the performance of the ceramic cups have been limited to studies relating to specific research or uses. No publication has summarized the accumulated knowledge of problems associated with the ceramic cups. This paper outlines the results and recommendations of earlier research into the uses and performance of the ceramic cups and describes some research on the limitations and precautions in using ceramic cup samplers for extracting dilute concentrations.

## LITERATURE REVIEW

In 1962, the use of ceramic cups for extracting soil-water solution were first introduced into the literature (Wagner 1962). Wagner outlined the sampler construction, sample retrieval methods, and attempted to show a relationship between soil moisture levels and the amount of sample pulled through the cups. He suggested further uses which included combining chemical data with neutron probe measurements and then estimating the volume of dissolved solids and nutrient concentrations on a "per acre" basis.

In a study investigating the weathering rates of granitic rock, ceramic cups were used to extract water samples from the soil (Wolff 1967). Wolff noted considerable contamination in the samples resulting from the cups themselves which was discovered by leaching one liter of distilled deionized water through new cups. Wolff first flushed the cups using 1N hydrochloric acid. No mention was given in the article as to the volume of acid or rinse water used in the pre-treatment. After rinsing, Wolff noted that cations in 1000 ml of distilled deionized water passing through the cup increased by 3.2 mg/l for calcium, 0.2 mg/l for aluminum, 2.2 mg/l for magnesium and 0.6 mg/l for sodium. The experiment demonstrated that flushing with 1N HCl will not remove all contaminants from the ceramic cup matrix.

A pretreatment procedure to reduce contamination was outlined by Grover and Lamborn in 1970. Cups were leached with 200-300 ml of distilled water and progressive aliquots of leachate were collected

and analyzed for calcium, sodium and potassium. Another set of tubes were leached with 200 ml of 1N HCl, and rinsed with 20 ml of distilled water to remove the acid. Progressive aliquots were collected (in the same manner as the run with distilled water) and analyzed for the cation concentrations. Contamination by Na and K was substantially decreased by acid leaching, but Ca contamination still remained after the acid leaching. One new ceramic cup was crushed and soaked with dilute acid, in which 0.35 g of Ca was solubilized in the acid.

Wood (1973) described a method to obtain water samples from great depths by using the ceramic cups in conjunction with a pressurized gas system. This method withdrew samples from depths as great as 108 feet. No mention was made in the article of possible contamination problems inherent in the cups. In published comments on the Wood article, England (1974) warned future users of the problems possible in collection of samples from ceramic cups resulting from various soil moisture levels and contamination from the cups themselves. England suggested that water collected from soil macropores at low suctions may be chemically different than samples collected from micropores at higher suctions. It was England's opinion that the cups must have some cation exchange capacity, but he did not cite any research to substantiate his claim.

Wood (1974) suggested that the ion exchange of the ceramic could also change the composition of the sample. He claimed that  $H^+$  ions would occupy the exchange sites in the cup matrix during flushing, and would be removed by flushing with tap water. He felt the Cation Exchange Capacity (CEC) was relatively small, thus the

CEC would affect the sample when only a volume of few milliliters were to be passed through. But, if greater volumes of sample were to be passed through, the CEC would be quickly saturated and the remainder of the samples would be representative of the soil-water solution. Finally, Wood suggested that suction levels be carefully controlled so that the soil pore size being sampled would remain uniform.

In a recent study, investigations into the interactions of major anions were made as well as evaluations of the mechanical performance of the cups (Hansen and Harris 1975). Initial tests were done to determine intake rates of the cups in saturated conditions. The authors used beakers of water as the source and measured the rates of intake on several lots of ceramic cups, using a constant vacuum source as well as a decreasing vacuum (usually found in field use). Samples showed a wide range of volumes collected, with some differences as great as six fold. Variation was attributed to cup construction. Cups with an average thickness of 1.9 mm collected a volume of about 520/ml hour, at a vacuum level of 0.7 atmosphere. The intake rate was found to be faster in solutions containing high levels of nitrate and phosphate, although the authors were unable to suggest any cause for this behavior.

In other tests concerning the interaction of anions with the cups, 0.03 mg phosphorus was added to the solution from new cups when 616 ml of distilled water were leached through. No acid was used in any of the leaching. However, cups showed an ability to absorb phosphorus, but not nitrates. Cups that were augmented artificially with phosphorus did not release much of the phosphorus when leached with deionized

water, suggesting the phosphorus was bound in the cup matrix. Some evidence of selective retention was shown, as concentrations of the nutrient solution increased with time during sample extraction.

Hansen and Harris (1975) studied the performance of ceramic cups from a mechanical aspect. Samplers which were kept in a field situation for 4 months showed a reduced intake rate of 28 percent at constant suctions. In another group of samplers kept in the field for a full year, intake rates were reduced up to 60 percent. They suggested that the variation in sample nutrient concentration found between fast and slow intake systems could be attributed to fast samplers taking a disproportionately large part of their sample early in the sampling period, when nutrient concentrations are relatively low, whereas the slower samplers would still be drawing samples when the solutions were more concentrated.

The authors suggested the following precautions in using the ceramic cups:

1. Use cups with uniform intake rates.
2. Take samples which represent the actual soil water drainage such that each pore size and each corresponding nutrient concentration is represented.
3. Some attempt should be made to quantitatively determine the bias between the concentration of the samples and the actual soil-water solution.
4. Sampling periods should be as short as possible to reduce the bias.

5. Because the amount of physical obstruction in the pores by soil particle should change with time, so should the performance and reliability of the samples.

Other studies have been done to identify the variability of concentration due to time of extraction (Severson and Grigal 1976). Ceramic cup samplers were inserted into soil columns. Two and a half centimeters of distilled water was added to each column every 72 hours. The experimental design included extractions of at least 10 milliliters during each 72-hour sampling period. No noticeable trends were noted in concentration throughout 16 successive 72-hour periods. However, sample concentration was directly correlated with time required to extract the samples. The authors presented the following results with possible inferences:

1. Samples collected in short time periods represent solutions moving through the soil rapidly and held at tensions of 0.1 bar or less. These samples were lower in concentration (P, Ca and K) than the samples collected at higher tensions. The authors considered these samples, collected at low tensions, to most correctly represent the actual soil water available in the leaching process.

2. Samples extracted over longer periods represent solutions held at higher tensions and may not represent the soil water concentrations actually available as drainage. Samples at tensions greater than 1/3 atmosphere hold little interest to the investigator studying leaching losses because of the low hydraulic conductivity.

The authors presented the following recommendations in using the ceramic cups:

1. Use a constant sampler tension.

2. Use a tension of 0.1 bar or less to more accurately represent solution available for leaching losses.

A numerical method for evaluation of moisture flow towards ceramic cups samplers was developed for a series of hypothetical soil conditions (van der Ploeg and Beese 1977). The authors have considered several sources of possible sample variability and cite the following examples:

1. Accurate determinations of leaching of soil nutrients depends on a known percolation rate through a soil profile. Problems exist when one considers that soil systems are transient and that soil water levels as well as concentration levels show gradients throughout a soil profile.

2. A suction unit in operation in the soil profile will act as a sink for the soil solution, and will distort the existing gradient patterns and percolation rates.

3. The composition of a collected sample is not representative of one particular depth, but reflects average composition of the surroundings. Depending on the amount of suction applied, the sample may be larger or smaller. Only in the case where the composition of the soil solution is the same throughout the soil profile is the composition of the collected sample independent of the size of the sample and the way it was collected.

The authors did not try to study or model the impacts of extraction techniques on sample composition. The objective of the model was



to relate sample size, applied vacuum, and the percolation rate of the unextracted soil. Few substantial conclusions could be drawn from the model, other than to suggest that percolation rates be determined independently from sample collection.

Recently, expanded use of ceramic cups has been investigated. An attempt was made to sample bacterial levels in soil water (Dazzo and Rothwell 1974). Bacteria appeared to be absorbed on the cup sides, to remain in the cups for months, and to be selectively withheld on the cup surfaces. The authors concluded that ceramic cups samplers could not be used to determine accurate levels of bacteria in soil water.

In order to remove the problems of ceramic contamination in the soil water extractions, several new devices have been explored to remove soil water for analysis. All-plastic suction lysimeters have been tried. These show much less contamination problems and are less selective in respect to suspended particle size (Quin and Forsythe, 1976). The plastic extraction cups were shown to not plug up as the ceramic cups tend to do, as well as not contributing much contamination to the water samples.

Another product now being tested is hollow fiber tubing (Levin and Jackson 1977). In a limited experiment, the authors demonstrated that samples extracted from hollow fibers were comparable to samples from ceramic cups, with the possible exclusion of nitrates. It was recommended that ceramic cup samplers be continued as the preferred method of extraction in the field, due to the difficulties in installing the hollow fiber devices.

Currently, the ceramic cup is still the most commonly used device for sampling soil water chemistry. However, the potential for sampling error has become more understood in recent years. The ceramic cups can yield valid data when the user has been made aware of the limitations and precautions to be exercised when sampling.

## OBJECTIVES

With the continued interest in the uses and performance of ceramic soil-water samplers, a set of laboratory and field experiments were designed to further evaluate the sampling reliability and reproducibility of sample concentrations resulting from soil-water extractors.

Specifically, experiments were designed to:

1. Determine the effect of a number of years of field installation on sample chemistry;
2. Determine the effects and persistence of variation of sample chemistry from pretreatment of ceramic cups with dilute HCl;
3. Determine the viability of reflushing with dilute HCl and distilled-deionized water older cups in order to return them to initial performance capacities;
4. Determine, under field conditions, the impact on a sampling site by repeated sampling; and
5. Determine, under field conditions, any differences in extractions from new tubes and older tubes located in the same sampling site.

## METHODS

Ten new water extraction tubes were constructed using 2-foot lengths of PVC tubing and new ceramic cups (Figure 21). One liter of 1N HCl were poured into the cups and allowed to drain. After leaching with the dilute acid, 1 liter of distilled water was flushed through the tube assemblies.

Ten 6 year old tubes were randomly selected from tubes used in a field study in Wyoming. Each PVC tube was cut to a length of 2 feet to insure consistent amounts of suction and volume between the various tube types. Each field tube was immersed for 5 minutes into a cylinder of distilled water to remove soil from the external part of the cup. Following the soak, the tubes were quickly wiped free of any remaining soil. To insure that no large material remained within the tubes, each tube was washed inside with distilled water. Initially, no distilled water was flushed through the ceramic cups.

The identical treatment was applied to a set of 10 1-year old tubes that were removed from the forested site of the Wyoming field project.

Ten sampling units were built at the Utah Water Research Laboratory, Logan, Utah in January 1978. Each unit consisted of a 5 gallon plastic bucket filled with 35 pounds of air dry, washed masons sand. Each unit was punctured on the bottom to facilitate drainage. Buckets were prerinsed and scrubbed with a solution of dilute HCl and triple rinsed with distilled water. After sealing the drain plugs, the buckets were filled with sand. A solution of known concentration was prepared (Table 10).

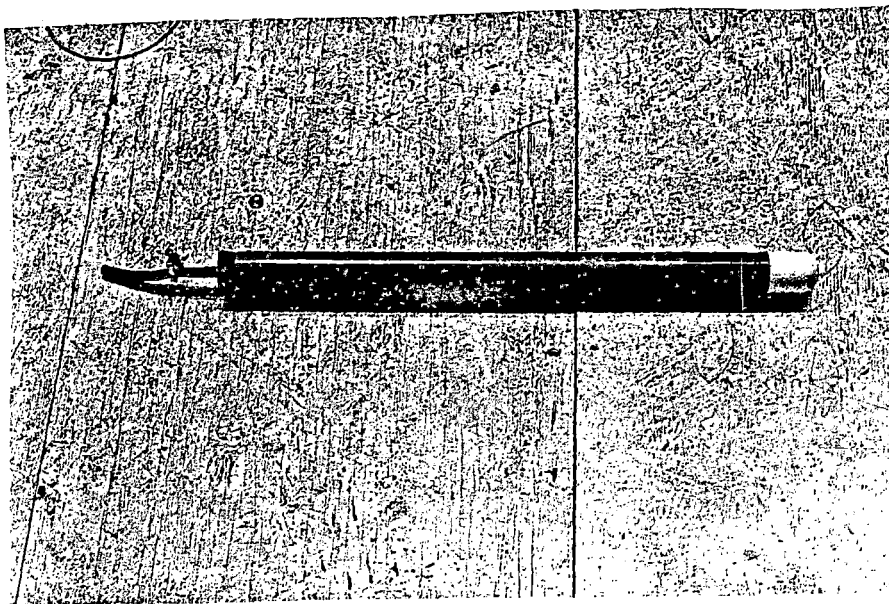


Figure 21. Soil-water sampler, consisting of a ceramic cup, 2-foot PVC tube and stopper assembly.

Table 10. Concentration of nutrient solution.

Ion	Estimated concentration (mg/l)	Measured concentration (mg/l)	Source of ion
Ca <sup>++</sup>	5.0	5.0	CaCO <sub>3</sub>
Mg <sup>++</sup>	1.0	.86	MgCl <sub>2</sub> ·6H <sub>2</sub> O
Na <sup>+</sup>	5.0	5.5	NaCl
NO <sub>3</sub> -N	1.0	1.1	KNO <sub>3</sub>
PO <sub>4</sub> -P	0.1	.09	KH <sub>2</sub> PO <sub>4</sub>
K <sup>+</sup>	2.8	2.5	(KNO <sub>3</sub> +KH <sub>2</sub> PO <sub>4</sub> )

Each bucket of sand was saturated with the nutrient solution and weighed. Sand and solution in each bucket were stirred to achieve homogeneity. A sample of the nutrient solution was drained off for later analysis.

SET I and II: Ten 6-year old cups and 10 1-year old cups removed from the field were compared with the new pretreated cups to determine any variation in volume collected and changes in chemistry due to field use.

One new tube, one 6-year old tube and one 1-year old tube were placed in each of the 10 sand-filled buckets (Figure 22). After installation, suction was applied to each assembly using a vacuum with an inline gage. Tubes were brought to a suction level of 17 inches of mercury (0.57 bars) and sealed with hose clamps. After 1 day, tubes were opened and water samples were drawn using a piece of Tygon tubing and an inline water trap (Figure 23). Each sample

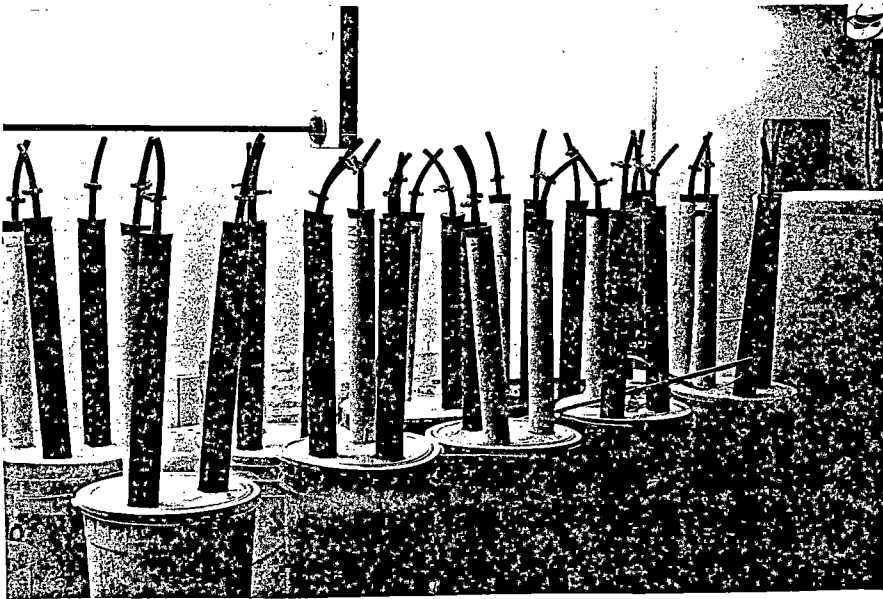
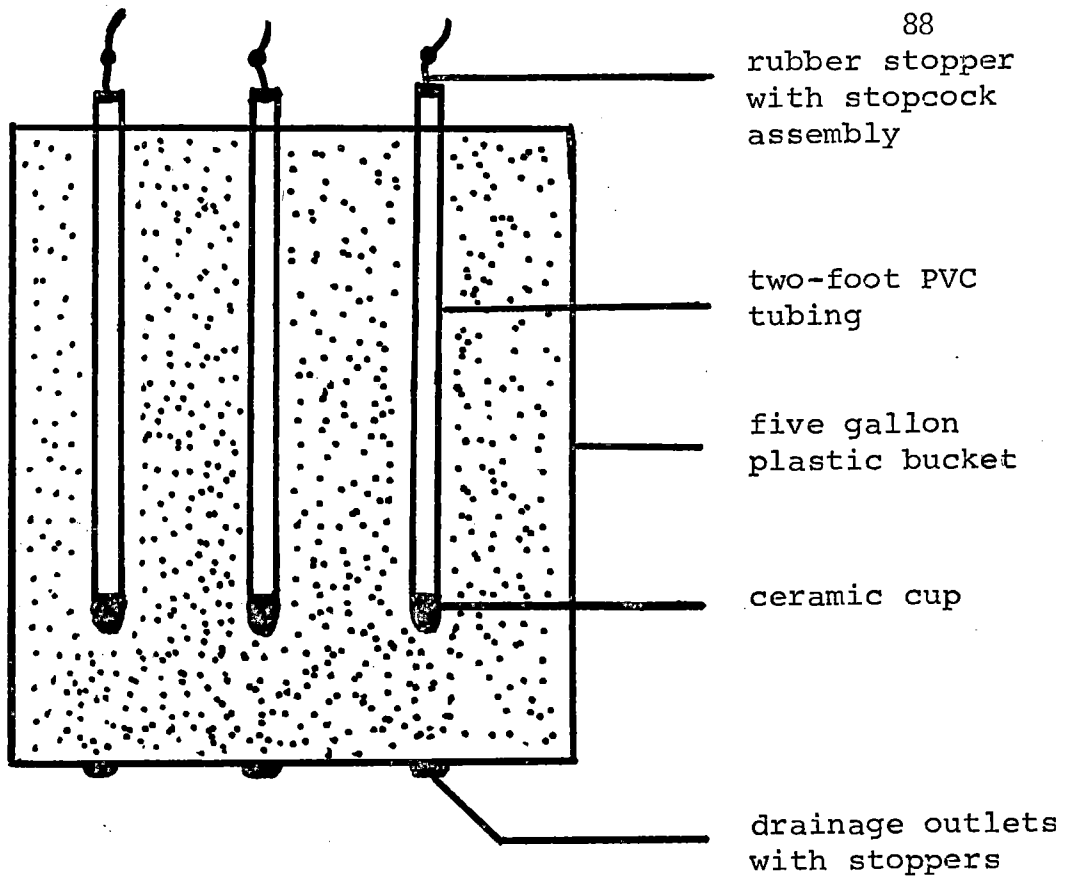


Figure 22. Laboratory sampling unit.

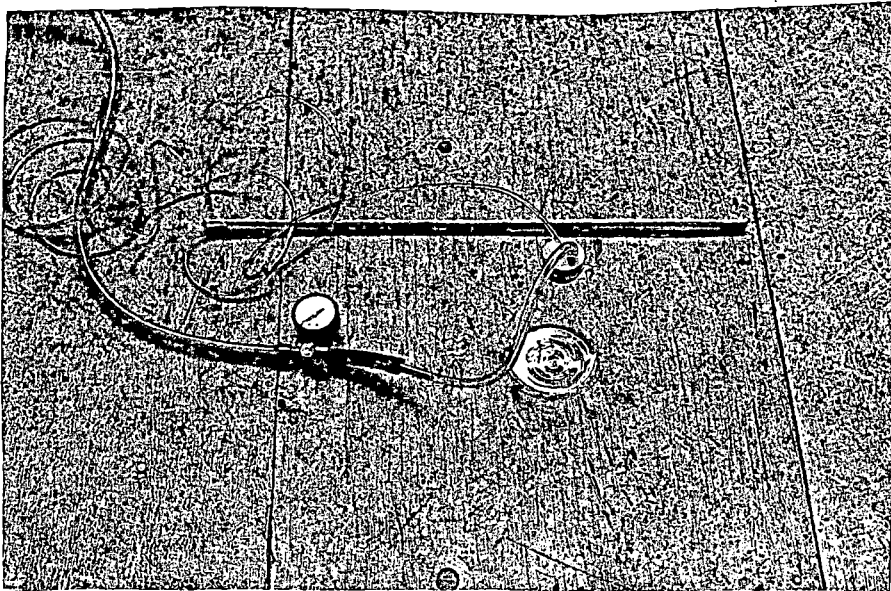


Figure 23. Sample collection system, consisting of vacuum line with inline gage, water trap, and extractor rod.



volume was recorded for the set (SET I samples). Between collection of each sample, the vacuum assembly was rinsed with distilled water to reduce cross-contamination. Samples were collected in triple-rinsed Nalgene bottles and immediately refrigerated. Within 2 days the samples were analyzed for the six chemical parameters. After extraction of the first set of samples, suction was reapplied and the buckets were weighed. After 1 day samples were again collected and analyzed (SET II).

SET III and IV: Ten new, 10 1-year old, and 10 6-year old cups removed from the field were flushed with dilute HCl and rinsed with distilled water and replanted into the laboratory units. Extractions were compared between sampler types and drainages.

After the first two sets (SET I and SET II) of samples were collected, all of the tubes were removed from the buckets. The 30 tubes were leached with 1N HCl and rinsed with 1 liter distilled water. In each sand bucket, stock solution was added to reach saturation and the sand was stirred to achieve homogeneity within each bucket. Suction was applied at a level of 17 inches of mercury. After 6 hours, samples extracted through the cups and drainage solution from the buckets were collected. Drainage water was filtered with membrane filter apparatus. All samples were refrigerated until analysis (SET III samples).

All 30 tubes were again removed from the buckets and stock solution was added and the sand was stirred to regain saturated conditions. Tubes were reinstalled into their respective buckets without any pretreatment applied to the tubes after the SET III samples were extracted through them. A uniform suction of 17 inches of mercury

was applied to all tubes. Samples were again collected after 6 hours (SET IV samples).

SET V: Nine new cups were placed into three laboratory units to detect variability in chemistry of samples extracted through new cups.

In a control experiment nine new laboratory tubes were withdrawn from the sampling buckets and flushed and rinsed. Three tubes were placed in each of three saturated buckets and identical suction levels (17 inches of mercury) were applied to each tube. After 6 hours, samples were collected from each tube and analyzed (SET V).

#### Chemical Analyses

The four major cations were analyzed on a Varian Atomic Absorption Spectrophotometer. Magnesium was measured using atomic absorption techniques, and calcium, sodium, and potassium were measured using the flame emission mode. Nitrates were measured using the cadmium reduction method on a Technicon Auto Analyzer. Ortho-phosphates were measured using the ascorbic acid method and read on a Bausch and Lomb Spec 70 spectrophotometer. All tests were performed according to Standard Methods (American Public Health Association 1975).

#### Soil Conditions

Several parameters of soil-water status were determined in the following ways.

Bulk density of the sand was determined by collecting samples of air dry sand from each of the 10 buckets, and filling a 1 liter graduated cylinder to the one liter line. Each cylinder was weighed and the bulk density was calculated using the following formula:

$$\text{Bulk density} = \frac{\text{weight 1000 ml air dry sand}}{\text{volume 1000 ml air dry sand}}$$

$$= \text{grams/ml} = \text{grams/cm}^3$$

Volumetric water content was calculated by the following method: Each bucket was filled with nutrient solution until the surface of the sand glistened. Each bucket was then weighed. The difference between the initial air dry weight of the system and the weight of the system at saturation was due to the addition of the water. Using the relationship 1 ml  $\text{H}_2\text{O}$  = 1 gram, the volume of the added water was calculated. Combining with the bulk density, the two calculations provided the necessary data for the determination of the volumetric water content,  $\theta_w$ .

$$\theta_w = \frac{\text{volume water added}}{\text{volume dry soil}}$$

Mass water content was calculated using the following formula:

$$\theta_w = \frac{\text{mass water added}}{\text{mass dry soil}}$$

### Statistical Design

Throughout all experiments, randomized block analysis of variance techniques were employed. To determine significant differences between specific tube types, the least significant difference (LSD) technique was used. For example, in SET I and SET II comparisons, the following statistical design was used:

Number of treatments: 6 (two extractions from new, 1-year old field and 6-year old field, respectively)

Number of blocks: 10 (each bucket considered a separate unit)

degrees of freedom:

<u>source</u>	<u>degrees of freedom (d.f.)</u>
treatment	$(6 - 1) = 5$
block	$(10 - 1) = 9$
error	$(5 \times 9) = 45$
total:	$6 \times 10 - 1 = 59$

statistics:

$$F = \frac{\text{treatment mean square}}{\text{experimental error mean square}}$$

If  $F$  exceeds  $F_{(1-a)(v_1, v_2)}$  where  $F = 2.43$  @ 95% sign.

$a = .05$  and  $v_1 = (\# \text{ treatments} - 1) = 5$

$v_2 = (\# \text{ blocks} - 1) \times (\# \text{ treatment} - 1) = 45$

then it is concluded that there are significant differences between treatments.

The least significant difference (LSD) technique was employed only if the  $F$  test showed a significant difference between treatments. It is defined by the equation:

$$LSD = t_{(1-a/2)(v)} \times \sqrt{2/n \times MSE}$$

where:  $\alpha = .05$  and  $t^*$  is at probability of .975,

$v = \text{d.f. of the error term; in the above example, 45,}$

$n = \text{number of blocks}$

$$*t_{.975 (45)} = 2.014$$

MSE = mean square error

If any two of the means differ by the LSD or more, then the difference is considered significant at probability greater or equal to 95 percent.

### Missing Data

When just one data point was missing in a treatment, instead of discarding the entire block, an estimation procedure was used to predict the missing value (Ostle and Mensing 1975). The missing observation was estimated by the equation:

$$M = (tT + bB - s)/(t-1)(b-1)$$

where:  $t = \text{number of treatment,}$

$b = \text{number of blocks,}$

$T = \text{sum of observations with the same treatment as the missing data,}$

$B = \text{sum of observations in the same block as the missing data, and}$

$S = \text{sum of all actual observations.}$

The data were then analyzed for variance as described above, with the following changes to avoid biased results:

A correction for bias "Z" is determined by the equation:

$$Z = \frac{(B - (t-1)M)^2}{t(t-1)}$$

The treatment of square, TSS, is redefined as TSS', where  $TSS' = TSS - Z$ . Experimental error degrees of freedom is reduced by one.

### Field Study

Six 6-year old tubes were randomly removed from treatment sites at the Union Pass Study. The tubes were replanted adjacent to the six 6-year old tubes located in the undisturbed forest site. Twelve new tubes were also installed in the same site. Samples were collected along with the samples from the Union Pass Study in the summer of 1977.

A statistical analysis of data from these samples could reveal the source of any shift in nutrient concentrations in the extractions over time. A significant difference between original tubes and reinstalled old tubes would indicate a change in immediate sampling location, suggesting that repeated sampling may alter the sampling site by creating a nutrient sink. But if no difference were noted between old reinstalled tubes and original tubes and a significant difference was noted between the old and new samplers, then this would indicate that the old samplers were no longer obtaining representative samples.

## RESULTS

### SET I and SET II: Comparison of sample volume and chemistry between leached new cups and 1 and 6-year old cups removed from the field

Samples were drawn from all 30 tubes to form SET I samples.

Immediately after collection, suction was reapplied to all 30 tubes and SET II samples were collected 1 day later. With the exception of one tube in SET II, both extractions produced complete sets of samples.

Sample volumes. All samples obtained in SET I were in the range of 500-750 ml (Appendix, Table 16). With the exception of one tube all samples in SET II were in the range of 450-750 ml. Means of the different volumes collected by each cup type are shown in column one of Table 6. The F test result of 0.52 implies that there is no significant difference in sample volumes extracted by cups of different lengths of field use, collected under saturated conditions of 1 day sampling periods

In a sampling period of 1 day, the reduced sampling intake rates due to plugging in the older cups (Hansen and Harris 1975) is not demonstrated because the soil was totally saturated, and it would be expected that the hydraulic head of the soil water would match the water level in the tubes. With new cups maintaining an initial sampling rate of approximately 520 ml/hour, as indicated by Hansen and Harris (1975), they would be expected to collect samples within the first few hours. With older cups, however, a reduction of sampling intake rate as high as 60 percent would still allow collecting a sample

Table 11. Summary of means and LSD from SET I and SET II samples.

Cup type	Volume (ml)	Chemical parameter (mg/l)					Number of samples
		Na	K	Ca	Mg	NO <sub>3</sub> -N	
<u>SET I</u>							
1-year old field	588	11.3	3.1	6.6	0.50	1.30	10
6-year old field	644	11.6	3.2	6.6	0.50	1.44	10
New lab	620	10.0	2.6	6.4	0.43	1.27	10
<u>SET II</u>							
1-year old field	608	11.6	3.1	7.6	0.46	1.17	9
6-year old field	641	11.8	3.3	8.1	0.49	1.24	10
New lab	614	10.6	3.0	7.7	0.46	1.17	10
F	0.52	4.35	14.0	12.2	5.4	29.3	
Results	insign.	sign.	sign.	sign.	sign.	sign.	
LSD	--	0.97	0.18	0.59	0.04	0.05	



whose volume would be comparable to the volume by a collected new cup. If the sampling period were reduced to 2 or 3 hours, a substantial reduction in the volume extracted through the older cups might be expected. However, in a field situation, when soils are often of much lower water content, and larger numbers of samplers are involved, the shorter sampling period is often impractical and may not produce sufficient volumes for lab analysis of a number of elements.

The SET II samples were collected under conditions considered saturated because, although the buckets did not receive any additional nutrient solution between the first and second set of samples, a distinct wetting front which was above the level of the ceramic cups was noted in the plastic buckets during the sampling period of the second set.

All samples extracted through the ceramic cups showed no noticeable turbidity or color, nor did they contain any suspended solids which would interfere with analytical methods.

Sodium concentrations. A significant difference resulted between concentrations of sodium obtained from different cup types (Column two of Table 11 and Appendix, Table 17). The F-test produced a significant value of 4.35, suggesting that there was at least one difference in mean sodium concentrations between cup types.

Both 1-year old and the 6-year old field cups produced samples which were significantly higher in sodium concentration than the new lab cups. This occurred in both sample SETS I and II. Samples from the 1- and 6-year old field cups were the same. Sample concentrations

were seen to increase slightly from SET I to SET II, but this increase was not significant.

Potassium levels. An analysis of variance of the sample concentrations showed that significant differences occurred between different cup ages. The F test produced a value of 14.0 (Column three of Table 11 and Appendix, Table 18).

Both the 1-year old and the 6-year old cups produced mean values that were significantly higher than the new lab cups in SET I (Table 11). However, in SET II only the mean of the 6-year old cups was significantly higher than that from the new lab cups. It is also worth noting that in SET II, the 6-year old cups were significantly higher in concentration than the 1-year old cups.

Significant increase was also noted in the new lab cups between SET I and SET II, although no change was noted in the field cups.

Magnesium concentrations. Again, significant differences were noted in the treatment means as shown by the F test value of 5.4 (Column five of Table 11 and Appendix, Table 19). The new lab cups were significantly lower than the 1- and 6-year old field cups within SET I. However, in SET II no differences were noted between any of the cup types.

Although not statistically significant, the levels of Mg were shown to decrease from SET I and SET II in the 1- and 6-year old field cups, whereas in the new lab cups the concentrations were seen to increase.

Calcium concentrations. Within each set, no significant differences in calcium concentrations were noted between cup types.

However, the F test value of 12.2 resulted from significant increases in calcium concentrations in all cup types from SET I to SET II (Column four of Table 11 and Appendix, Table 20). This increase, between SET I and SET II, may have been due to the contribution of calcium from the masons sand, thus increasing the concentration in the stock solution. As seen in Table 11, this increase between sets was noted in all cup types.

Nitrate concentrations. Significant differences were again noted between cup types, as shown by the F test of 29.3 (Column six of Table 11 and Appendix, Table 21).

Extractions from the 6-year old field cups were significantly higher than both the 1-year old field and the new lab cup extractions. This relationship is also apparent in the second set of data. No difference is noted in nitrate levels between 1-year old field and new lab cups.

All cup types produced sample concentrations significantly higher in SET I than in SET II. Decreases in the second set may have been due to either biological activity or adsorption of the ion to the sand matrix or cup surface.

Ortho-phosphate concentrations. Initially the stock solution concentration prepared measured 0.09 mg/l  $\text{PO}_4\text{-P}$ . However, the drainage samples collected after SET I and SET II were extracted yielded undetectable (less than 0.01 mg/l) levels of ortho-phosphate, probably due to precipitation of  $\text{HPO}_4$  by the calcium in the sand. As can be seen in Appendix, Table 22 a few cup extractions showed measurable

phosphate levels, but due to the apparently rapid adsorption of the phosphate to the sand matrix and subsequent biological removal, the investigation into the behavior of low levels of phosphates was discontinued.

Summary of results (SET I and SET II). Ceramic cups which had been installed in the field 6 years produced samples with concentrations consistently greater or equal to those from ones which had been installed for 1 year. Correspondingly, cups which were in the field 1 year produced samples with concentrations greater or equal to those from new flushed and rinsed cups (with one exception, Ca). In general, longer field use of the cups resulted in higher concentrations of the measured parameters in the extracted samples (Table 11). Those differences in mean concentrations which were found to be statistically significant are indicated in Table 12 where the mean concentrations for all three treatments have been compared.

Soil parameters. Bulk density of masons sand averaged  $1.38 \text{ g/cm}^3$ , with a range of  $1.36$  to  $1.40 \text{ g/cm}^3$  (Table 13). Volumetric water content at saturation was determined to be about 39 percent with a range from 34 to 42 percent.

Volumetric water content was approximately 23 percent after the first extraction (Table 13). Thus, all extractions in SET I and SET II were at low levels of soil-water tension and were at or near saturated conditions.

Table 12. Contrasting of mean concentrations from SET I and SET II.

Cup comparison	Chemical parameter				
	Na	K	Ca	Mg	NO <sub>3</sub> -N
<u>SET I</u>					
S $\geq$ N	>	>	$\equiv$	>	>
S $\geq$ O	$\equiv$	$\equiv$	$\equiv$	$\equiv$	>
O $\geq$ N	>	>	$\equiv$	>	$\equiv$
<u>SET II</u>					
S $\geq$ N	>	>	$\equiv$	$\equiv$	>
S $\geq$ O	$\equiv$	>	$\equiv$	$\equiv$	>
O $\geq$ N	>	$\equiv$	$\equiv$	$\equiv$	$\equiv$

S = 6 year old field cups

O = 1 year old field cups

N = New lab cups

$\alpha$  = .05

> = Significantly greater than

< = Significantly less than

$\equiv$  = Statistically the same

Table 13. Soil parameters of masons sand.

Soil parameter	Mean	Range	Standard deviation
Bulk density ( $\rho_B$ )	1.38	1.36-1.40	0.011
Volumetric water content saturation $\theta_W$	0.39	0.34-0.42	0.032
Volumetric water content (after removal of SET I samples) $\theta_W$	0.23	0.18-0.27	0.031

SET III and SET IV: Comparison of sample concentration between leached new cups and leached 1 and 6-year old cups

Before extracting SET III samples, all cups were removed from the buckets, flushed with 1N HCl, and rinsed with distilled water.

SET III and IV samples were taken to determine whether flushing and rinsing old cups would return them to initial sampling capacities, such that extracted samples would be chemically indistinguishable from ones collected by new cups. Furthermore, drainage samples of the soil-water were collected simultaneously with SET III and SET IV samples to study how well the cup samples represented the soil-water solution.

Sodium concentrations. Samples both from drainage water and extracted samples were significantly higher than 5.5 mg/l (Table 10), suggesting that sodium was still being leached from the sand media (Table 14 and Appendix, Table 24). In the first extractions (SET III), all cup types produced samples that were 9 to 11 percent lower in

Table 14. Summary of means and LSD from SET III and SET IV samples.

Cup type	Chemical parameter (mg/l)									
	Na	% differ- ent from drainage	K	% differ- ent from drainage	Ca	% differ- ent from drainage	Mg	% differ- ent from drainage	NO <sub>3</sub> -N	% differ- ent from drainage
<u>SET III</u>										
1-year old field	6.8 <sup>+</sup>	- 9	1.5 <sup>+</sup>	-44	6.0	- 6	0.55	- 5	0.94 <sup>+</sup>	-11
6-year old field	6.7 <sup>+</sup>	-11	2.0 <sup>+</sup>	-26	6.1	- 5	0.56	- 3	0.98 <sup>+</sup>	- 8
New lab	6.8 <sup>+</sup>	- 9	1.9 <sup>+</sup>	-30	6.0	- 6	0.54	- 7	1.03 <sup>+</sup>	- 3
Drainage water	7.5		2.7		6.4		0.58		1.06	
<u>SET IV</u>										
1-year old field	7.3	0	2.2 <sup>+</sup>	-21	6.6	+ 3	0.60	+ 5	1.00 <sup>+</sup>	+ 1
6-year old field	7.0	- 4	2.5 <sup>+</sup>	-11	6.1	- 5	0.56	- 2	0.94 <sup>+</sup>	- 5
New lab	6.8	- 7	2.4 <sup>+</sup>	-14	6.4	0	0.58	+ 2	0.98	- 1
Drainage water	7.3		2.8		6.4		0.57		0.99	
F	2.13		59.0		1.16		0.8		6.68	
Results	sign.		sign.		insign.		insign.		sign.	
LSD	0.58		0.16						0.04	

<sup>+</sup>significantly different from drainage water

concentration than the drainage water. However, no significant differences were noted among the three cup types themselves in SET III. In SET IV, all cup types again showed no significant differences among themselves, and no longer were the cup extracts significantly lower than the drainage samples.

Potassium concentrations. The concentration of the nutrient solution was determined to be 2.5 mg/l (Table 10). As can be seen in Table 14, both sets of drainage water were significantly higher than the initial concentration, suggesting that the sand was contributing potassium to the soil-water solution, as was also seen with sodium. In the first set of extractions (SET III), samples from all cup types were significantly lower than the drainages. Samples from the 1-year old cups were significantly lower than the extractions from the 6-year old and new cups. In SET IV, extractions from all cup types were again significantly lower than drainage water, and again no significant difference was noted between the lab cups and the 6-year old field cups.

The differences between the extractions and the drainages decrease from SET III to SET IV going from 26 to 44 percent to 11 to 21 percent (Table 14). This was also noted in the sodium concentrations. Also, as was noted in the sodium samples, no significant differences in potassium concentrations were noted between the new lab cups and the leached 6-year old cups. The significantly lower levels of potassium noted in both sets of samples from the 1-year old cups is not understood and can not be explained. For complete data listing, see Appendix, Table 25.



Magnesium concentrations. The concentration of the prepared nutrient solution was determined to be 0.86 mg/l Mg (Table 10). As can be seen in Table 14, all drainages and extracted samples were lower than the initial solution, thus showing that sand adsorbed Mg. However, no significant differences were noted between any cup type and drainages (Table 14 and Appendix, Table 26). The F test resulted in a value of 0.8, indicating that there were no significant differences between any of the treatments.

Calcium concentrations. The concentration of the prepared nutrient solution was determined to be 5.0 mg/l Ca (Table 10). As shown in Table 14 and Appendix, Table 27, all drainages and extracted samples were higher than the initial nutrient solution, suggesting the sand system was contributing to the available calcium to the soil-water solution. No significant differences were noted between cup types or drainages, as indicated by  $F = 1.16$ , as was also seen in the magnesium data.

Nitrate-nitrogen concentrations. The initial concentration of the nutrient solution was determined to be 1.10 mg/l  $\text{NO}_3\text{-N}$  (Table 10). In SET III all samples were slightly lower in concentration than the initial solution (Table 14). Statistically, some differences were noted between cup type (Table 14 and Appendix, Table 28), but these lack practical importance because usually the nitrate-nitrogen data would be reported with one less figure (either 0.9 or 1.0 mg/l). Also, the sampling method in field conditions is questionable due to the high chance of sample deterioration for nitrates while being held in the tube assemblies for several days. Considering these inherent problems

with sampling nitrate, the variation noted in the nitrate concentrations is considered negligible.

Summary of results (SET III and SET IV). No significant differences in sodium, calcium and magnesium concentrations were noted between extracts from the three cup types after all had been flushed with 1N HCl and rinsed with distilled water (Table 14).

However, potassium and nitrate concentrations showed some variability between cup types. In both SET III and SET IV, 1-year old cups collected extracts that were significantly lower in K concentrations than those from other cup types. As mentioned earlier, this phenomenon is not understood. Some statistical differences in nitrate concentrations were noted between cup types in SET III, but these differences were not evident in SET IV.

#### SET V: Comparison of extracts from new cups

The extracts from new cups showed very little variability in chemical concentrations. Due to the variability between laboratory units, statistical analysis was performed on sample sets of three from each unit. The highest coefficient of variation noted from any set of three samples was 9.1 percent, resulting from a data set of 0.6, 0.7, 0.6 mg/l Mg (Table 15). Other chemical parameters showed similar distributions (Table 15).

Table 15. Comparison of extracts from new acid-rinsed cups

Laboratory unit	Tube number	Na	K	Ca	Mg	NO <sub>3</sub> -N
1	1	6.3	2.5	7.3	0.7	1.0
	2	6.5	2.4	7.3	0.7	1.0
	3	6.4	2.4	6.8	0.7	1.0
MEAN		6.4	2.4	7.1	0.7	1.0
STANDARD DEVIATION		0.1	0.1	0.3	0	0
COEFFICIENT OF VARIATION		1.5%	2.3%	4.0%	0%	0%
Laboratory unit	Tube number	Na	K	Ca	Mg	NO <sub>3</sub> -N
2	1	6.6	2.4	6.7	0.7	1.0
	2	6.6	2.4	7.1	0.6	1.1
	3	6.6	2.3	6.8	0.6	1.0
MEAN		6.6	2.4	6.9	0.6	1.0
STANDARD DEVIATION		0	0.1	0.2	0.1	0.1
COEFFICIENT OF VARIATION		0%	2.4%	3.0%	9.1%	5.6%
Laboratory unit	Tube number	Na	K	Ca	Mg	NO <sub>3</sub> -N
3	1	7.2	2.3	6.4	0.6	1.0
	2	6.6	2.4	6.8	0.6	1.0
	3	7.1	2.5	6.9	0.6	1.0
MEAN		7.0	2.4	6.7	0.6	1.0
STANDARD DEVIATION		0.3	0.1	0.3	0	0
COEFFICIENT OF VARIATION		4.6%	4.2%	3.9%	0%	0%

### Field Study

Due to an unusually dry year at the Union Pass Site in the summer of 1977, the number of samples collected was severely reduced, due to a lack of available soil-water. Also, several tubes were damaged by rodents during the sampling periods. Many of the stoppers were gnawed and removed from the tubes, causing suction to be lost in the tubes.

Due to both problems, only a few samples were collected. With the limited amount of data collected, no interpretation or statistical analysis could be attempted with the field study data.

## DISCUSSION

Results from the preceeding experiments show that, when sampling dilute nutrient soil-water solutions, previous use of the ceramic cup may influence the concentration of the soil-water extracted through the cup.

The effects of flushing and rinsing the ceramic cups are demonstrated in SET III and SET IV. After treatment, the concentrations of extracted samples were less than those in the soil-water solution. However, after the first extraction following the flushing and rinsing, the solutions (SET IV) were found to more closely resemble the soil-water solution. The SET III and IV samples also showed that no significant difference was noted in sampled nutrient concentrations between old and new cups, once all have been leached with dilute acid and rinsed with distilled water (Table 14). Thus, after pretreatment, the performance of old cups was similar to new cups. This is probably due to flushing which returned all cups to a uniform level of active CEC. Initially, freshly leached cups will underestimate soil-water concentrations. This underestimation, due to adsorption, will disappear in following extractions as the CEC becomes satisfied. These results are in agreement with the earlier suggestion by England (1974) of a cation exchange capacity within the cup matrix, as well as the theory that flushing with dilute acid will quickly fill up the exchange sites with  $H^+$  ions (Wood 1974), which later will be flushed out with distilled water. However, when flushing with

distilled water, some  $H^+$  ions would be expected to remain on the site, due to lack of available cations for exchange. These sites appear to become satisfied with cations in the first sample extracted, thereby yielding a sample which is lower in cation concentration than the soil-water. Wood (1974) found that if he rinsed the cups with tap water after flushing and rinsing with HCl and distilled water, no significant difference in chemistry was noted between input and output water. One possible alternative to rinsing with distilled water would be to flush the cups free of acid with a solution similar to solutions being extracted in the field. Thus the  $H^+$  ions are replaced with representative cations. Unfortunately, this procedure is liable to cause a bias in the results as well, if the flushing solution is different from the soil-water. In contradiction to the earlier work of Grover and Lamborn (1970), the pretreated cups, when leached with 1 l. of 1N HCl and distilled water, did not contaminate the extracted solution with calcium. Instead, some calcium, although not statistically significant, appeared to be adsorbed by the cup matrix during the first extraction after pretreatment.

In SETS I and II, the 6 and 1-year old cups, after installation in the field, appeared to have the CEC satisfied. In evaluating the results of these sets, the new lab cups show a more marked change upward in mean concentration, from SET I to SET II than do the field cups. For example, in the case of potassium, extraction from 1 and 6-year old cups remained essentially the same in sample concentration, from SET I to SET II, while extractions from the new cups increased in

mean concentration by 15 percent. This change was also noted in a lesser degree in the sodium data.

No statistical difference in calcium concentration was noted between extracts from old and new cups. However, distinct differences in magnesium concentration were noted between extracts from old and new cups. Extracts from the new lab cups were significantly lower in concentration than the older cups in SET I, but in SET II, the mean concentration were seen to converge, and no significant differences existed between cup types.

One conclusion from the SET I and II data is that the older cups which have been used in the field may sample the soil-water solutions more accurately because of less influence of the CEC of the cups. This conclusion may be viable when continuous sampling is done under conditions where sampling time and intake rates do not impart any variation on sample content. However, this does not include most sampling conditions. With time, sampling rate can be reduced as much as 60 percent because the cups become plugged (Hansen and Harris 1975). This has been shown to change the accuracy of the sample when compared to available soil-water. Later research showed that longer sampling period lengths, under unsaturated conditions, will show greater concentrations in the extracted sample (Severson and Grigal 1976). In sampling periods of two classes, i.e., less than or greater than 40 hours, mean calcium and potassium concentrations were shown significantly different. Although older cups will be less affected by initial CEC requirements, the potential variability due to different sampling rates due to plugging has been shown to be much more important in most cases.

## RECOMMENDATIONS

Assuming that sampling period and vacuum levels are kept constant, major problems can exist due to unequal intake rates and CEC requirements between old and new cups. If tubes are left in a field situation more than four months, there is a good chance that the intake rates of the cups will be markedly changed (Hansen and Harris 1975). One possible alternative is to remove the field tubes before the start of a new sampling season and flush the cups outward to remove the plugging materials. This could be accomplished with dilute acid and distilled water, or with a solution which is similar to samples previously collected from the tube. The latter suggestion would reduce the plugging and may not seriously alter the CEC occupying the sites.

Other general suggestions summarized from previous work and from this research are:

1. Prerinse new cups with at least 1 l. of 1N HCl and 1 l. of distilled water. No calcium contamination was seen from new cups after this method of pretreatment;
2. In dilute systems, discard the first extraction sample after new cups have been leached with acid and distilled water, since the CEC will take up selected cations and cause the sample to underestimate the actual soil-water concentrations;
3. If you attempt to estimate leaching losses, use uniform suction levels which do not exceed the tension of the water available for leaching;



4. Use uniform sampling times, in conjunction with obtaining soil moisture levels with neutron probe or tensiometer measurements; when measuring leaching losses, do not attempt to collect samples from tensions greater than that of free drainage water just for the sake of obtaining samples. These samples would not accurately represent available soil-water solutions involved in the leaching process;

5. Check all new samplers for intake rate variations. Try to group similar cups;

6. On a rotating basis, check older tubes in the field for changes of intake rates. If plugging occurs, flush tubes outward until intake rates are increased to original specifications; and

7. Interpret nitrate data carefully, due to poor sampling conditions associated with extraction tubes.

Limitations in applications of these data. The interactions between soil-water solutions and the CEC of the ceramic cups have been demonstrated by the above data. However, it is important to note that these experiments were performed under conditions which would not always represent conditions found in the field. For example, the pH of the prepared nutrient solution was 5.4, similar to the pH noted in soils at the Union Pass study. The pH dependency of the CEC in the ceramic cups was not investigated, so these results can not be applied where there is a different range of pH, without further investigations.

This study focused on soil-water solutions with very dilute concentrations of the major cations and anions. When sampling soil-water solutions with higher concentrations, the impact of the CEC

probably would be considered negligible. But, where soil-water is even lower in concentration, the potential for misrepresentation caused by the CEC could be even higher than was noted in the preceeding experiments.

When using ceramic cups, the investigator must first evaluate the conditions for sampling. As the preceeding studies have shown, the investigator must take into account the possibilities for error and misrepresentation of soil-water. If a few precautions are taken, ceramic cups can be used with success, producing useful and valid information.

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## APPENDIX

Table 16. Sample volume of SET I and SET II, in milliliters.

Bucket	SET I			SET II		
	1-year old	6-year old	New Lab	1-year old	6-year old	New Lab
1	600	610	520	450	460	520
2	630	495	660	600	560	600
3	525	660	675	639*	700	700
4	225	650	660	590	680	650
5	710	620	630	700	710	640
6	600	750	540	750	700	680
7	600	695	700	500	670	675
8	690	560	525	660	680	610
9	750	775	590	650	550	575
10	555	630	700	550	700	490
Mean	588	644	620	608	641	614
Range of LSD						
Upper	670	726	702	691	723	696
Lower	506	562	537	526	558	531

LSD = 82  
Z = 133.7

#### Results of Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square
Total	504908	59	
Column	21770	5	4354
Row	112161	9	12462
Residual	370843	44	8428

F(Column) = 0.52  
F(Row) = 1.48

\*Estimated value

Table 17. Sodium concentrations in SET I and SET II, in mg/l.

Bucket	SET I			SET II		
	1-year old	6-year old	New Lab	1-year old	6-year old	New Lab
1	10.2	10.1	8.6	10.8	8.8	8.4
2	10.5	10.9	9.3	12.4	11.4	11.0
3	11.1	11.8	10.5	11.7*	12.3	10.0
4	10.9	10.1	10.5	10.8	10.0	11.2
5	10.6	12.7	9.0	12.4	13.6	10.7
6	10.6	13.4	10.4	9.2	12.9	11.5
7	10.3	10.2	10.4	12.0	12.4	11.6
8	12.5	11.9	11.5	12.4	11.1	12.0
9	12.5	13.3	9.4	10.6	13.1	9.2
10	13.3	11.8	9.9	13.6	12.2	10.6
Mean	11.2	11.6	10.0	11.6	11.8	10.6
Range of LSD						
Upper	12.2	12.6	10.9	12.6	12.7	11.6
Lower	10.3	10.6	9.0	10.6	10.8	9.6
LSD = 0.97						
Z = 0.25						

## Results of Analysis of Variance

<u>Source</u>	<u>Sum of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>
Total	102.8692	59	
Column	25.0773	5	5.01547
Row	26.8587	9	2.9884
Residual	50.6867	44	1.15197
F(Col) = 4.35			
F(Row) = 2.59			

\*Estimated value

Table 18. Potassium concentrations in SET I and SET II, in mg/l.

Bucket	SET I			SET II		
	1-year old	6-year old	New Lab	1-year old	6-year old	New Lab
1	3.2	2.9	2.6	2.8	2.9	2.7
2	3.0	3.2	2.6	3.1	3.0	3.2
3	3.2	3.3	2.7	3.2*	3.7	2.8
4	2.8	3.0	2.8	2.8	3.2	3.0
5	2.9	3.1	2.7	3.2	3.3	3.2
6	2.9	3.5	2.4	2.6	3.6	3.1
7	3.0	3.0	2.6	3.1	3.2	3.0
8	3.3	3.4	2.7	3.4	3.2	2.9
9	3.1	3.6	2.4	3.1	3.4	2.7
10	3.2	3.2	2.5	3.4	3.4	3.0
Mean	3.1	3.2	2.6	3.1	3.3	3.0
Range of LSD						
Upper	3.2	3.4	2.8	3.2	3.5	3.1
Lower	2.9	3.0	2.4	2.9	3.1	2.8

LSD = 0.185

Z = 0.0015

## Results of Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square
Total	5.3077	59	
Column	2.9566	5	0.59131
Row	0.4892	9	0.05436
Residual	1.8604	44	0.04228

F(Col) = 13.98

F(Row) = 1.29

\*Estimated value

Table 19. Magnesium concentrations in SET I and SET II, in mg/l.

Bucket	SET I			SET II		
	1-year old	6-year old	New Lab	1-year old	6-year old	New Lab
1	0.54	0.56	0.49	0.42	0.45	0.46
2	0.51	0.47	0.43	0.45	0.45	0.43
3	0.45	0.48	0.40	0.43*	0.51	0.40
4	0.49	0.48	0.43	0.40	0.45	0.47
5	0.48	0.47	0.41	0.54	0.54	0.51
6	0.43	0.52	0.39	0.35	0.50	0.48
7	0.48	0.46	0.43	0.46	0.52	0.48
8	0.53	0.50	0.48	0.53	0.46	0.48
9	0.60	0.59	0.43	0.50	0.54	0.45
10	0.49	0.48	0.38	0.48	0.44	0.40
Mean	0.50	0.50	0.43	0.46	0.49	0.46
<u>Range of LSD</u>						
Upper	0.54	0.54	0.46	0.49	0.52	0.49
Lower	0.46	0.46	0.39	0.42	0.45	0.42

LSD = 0.036

Z = 0.00037

## Results of Analysis of Variance

<u>Source</u>	<u>Sum of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>
Total	0.1503	59	
Column	0.04325	5	0.008649999
Row	0.03671	9	0.0040785
Residual	0.07113	44	0.0015935

F(Col) = 5.43

F(Row) = 2.56

\*Estimated value



Table 20. Calcium concentrations in SET I and SET II, in mg/l.

Bucket	SET I			SET II		
	1-year old	6-year old	New Lab	1-year old	6-year old	New Lab
1	6.6	6.8	6.4	6.7	7.1	7.2
2	6.4	6.2	6.2	7.7	7.5	7.3
3	6.3	6.7	6.2	7.5*	8.6	7.2
4	6.1	6.0	6.4	7.1	6.7	8.1
5	6.1	6.6	6.1	8.9	9.0	7.8
6	6.0	7.0	6.0	5.8	8.3	8.1
7	6.1	5.9	6.5	7.8	8.3	8.0
8	7.3	6.7	8.2	8.5	7.5	8.4
9	7.9	7.8	6.4	7.8	9.0	7.6
10	7.0	6.0	6.1	8.4	9.3	7.3
Mean	6.6	6.6	6.4	7.6	8.1	7.7
Range of LSD						
Upper	7.2	7.2	7.0	8.2	8.7	8.3
Lower	6.0	6.0	5.9	7.0	7.5	7.1
LSD = 0.59						
Z = 0.241						

## Results of Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square
Total	52.9185	59	
Column	26.1060	5	5.22120
Row	7.7979	9	0.8656
Residual	18.7804	44	0.4268

F(Col) = 12.23

F(Row) = 2.03

\*Estimated value

Table 21. Nitrate-nitrogen concentrations in SET I and SET II, in mg/l.

Bucket	SET I			SET II		
	1-year old	6-year old	New Lab	1-year old	6-year old	New Lab
1	1.30	1.44	1.24	1.13	1.18	1.12
2	1.28	1.44	1.26	1.24	1.27	1.21
3	1.29	1.35	1.28	1.16*	1.29	1.17
4	1.24	1.56	1.28	1.13	1.15	1.17
5	1.28	1.39	1.27	1.19	1.22	1.15
6	1.28	1.43	1.29	1.00	1.26	1.20
7	1.29	1.52	1.28	1.25	1.37	1.24
8	1.35	1.43	1.32	1.17	1.16	1.15
9	1.35	1.47	1.25	1.14	1.30	1.14
10	1.42	1.34	1.24	1.28	1.25	1.16
Mean	1.31	1.44	1.27	1.17	1.24	1.17
<u>Range of LSD</u>						
Upper	1.36	1.49	1.32	1.22	1.30	1.22
Lower	1.26	1.38	1.22	1.12	1.19	1.12
LSD = 0.052						
Z = 0.0115						

## Results of Analysis of Variance

<u>Source</u>	<u>Sum of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>
Total	0.68223	59	
Column	0.487797	5	0.09756
Row	0.036314	9	0.00403
Residual	0.14660	44	0.00333
F(Col) = 29.28			
F(Row) = 1.21			

\*Estimated value

Table 22. Orthophosphate concentrations in SET I and SET II, in mg/l  $\text{PO}_4\text{-P}$ .

Bucket	1-year old	6-year old	New Lab	1-year old	6-year old	New Lab
1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
2	0.02	<0.01	<0.01	<0.01	<0.01	<0.01
3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
4	0.10	0.10	<0.01	<0.01	0.06	<0.01
5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
6	<0.01	<0.01	<0.01	<0.01	0.03	<0.01
7	<0.01	0.08	<0.01	<0.01	0.04	<0.01
8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
9	<0.01	<0.01	<0.01	<0.01	0.05	<0.01
10	<0.01	0.09	<0.01	<0.01	<0.01	<0.01

Table 23. Soil conditions.

Bucket	System Weight* (kg) Air Dry	Water Added to Saturate System (kg)	Volumetric <sup>=</sup> Water Content @ Saturation	Volume Water <sup>+</sup> Removed-SET I	Resulting <sup>#</sup> Volumetric Water Content
1	17.69	3.83	0.33	1730	0.18
2	17.59	4.60	0.40	1785	0.25
3	17.77	5.02	0.44	1860	0.27
4	17.77	4.67	0.41	1535	0.27
5	17.77	4.59	0.40	1960	0.22
6	17.74	4.54	0.39	1890	0.23
7	17.60	4.79	0.42	1995	0.24
8	17.66	4.56	0.40	1775	0.24
9	17.63	4.31	0.37	2115	0.19
10	17.60	4.64	0.40	1885	0.20

= Based on a soil volume of 11500 cm<sup>3</sup>; 15.87 kg sand @ bulk density = 1.38 cm<sup>3</sup>/g

+ Total volume removed from sample system through extraction tubes (SET I)

# Soil moisture available for SET II extractions

\* Weight of 15.87 kg sand plus bucket, cover, extraction tubes and stoppers

Table 24. Sodium concentrations in SET III and SET IV, in mg/l.

Bucket	SET III				SET IV			
	Drain- age	6-year old	New Lab	1-year old	Drain- age	6-year old	New Lab	1-year old
1	8.2	7.1	6.8	7.2	7.4	6.9	6.9	6.8
2	6.7	7.0	6.2	6.6	6.6	6.1	6.3	6.0
3	7.5	6.8	6.8	6.4	7.6	7.6	7.6	7.2
4	6.3	5.8	5.7	6.0*	6.3	6.1	6.2	5.8
5	6.4	6.1	5.9	5.7	6.4	6.2	5.8	6.0
6	7.0	6.4	6.5	6.8	8.3	8.4	7.1	8.4
7	8.9	7.7	8.4	6.7	6.8	7.1	6.4	6.6
8	6.8	5.8	6.0	6.0	6.8	6.5	6.1	6.5
9	9.8	8.0	9.0	9.4	10.0	8.8	8.6	12.7
10	7.6	6.5	6.4	7.5	7.2	6.6	7.0	7.3
Mean	7.5	6.7	6.8	6.8	7.3	7.0	6.8	7.3
<u>Range of LSD</u>								
Upper	8.1	7.3	7.3	7.4	7.9	7.6	7.4	7.9
Lower	6.9	6.1	6.2	6.2	6.8	6.4	6.2	6.8

LSD = 0.58

Z = 0.57000

## Results of Analysis of Variance

<u>Source</u>	<u>Sum of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>
Total	107.48600	79	
Column	6.24680	7	0.892399
Row	74.69600	9	8.299500
Residual	25.97630	62	0.418970

F(Column) = 2.13

F(Row) = 19.81

\*Estimated value

Table 25. Potassium concentrations in SET III and SET IV, in mg/l.

Bucket	SET III				SET IV			
	Drain- age	6-year old	New Lab	1-year old	Drain- age	6-year old	New Lab	1-year old
1	2.7	1.9	1.9	1.5	2.7	2.4	2.6	2.2
2	2.5	1.8	1.9	1.4	2.7	2.2	2.2	2.0
3	2.6	2.0	1.8	1.5	2.6	2.2	2.3	2.1
4	2.6	1.9	1.8	1.4*	2.6	2.5	2.4	1.5
5	2.4	2.1	1.8	1.6	2.7	2.6	2.5	2.3
6	2.4	2.0	1.6	1.5	2.8	2.6	2.2	2.4
7	3.0	1.8	1.7	1.3	2.7	2.3	2.3	1.9
8	2.6	2.1	1.8	1.6	2.6	2.3	2.2	2.2
9	3.3	2.5	2.2	1.6	3.3	3.0	3.1	3.2
10	3.2	2.4	2.1	1.7	2.9	2.5	2.4	2.3
Mean	2.7	2.0	1.9	1.5	2.8	2.5	2.4	2.2
Range of LSD								
Upper	2.9	2.2	2.0	1.7	2.9	2.6	2.6	2.4
Lower	2.6	1.9	1.7	1.4	2.6	2.3	2.3	2.0

LSD = 0.16

Z = 0.24100

## Results of Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square
Total	18.12380	79	
Column	12.73850	7	1.819790
Row	3.19778	9	0.355530
Residual	1.94600	62	0.031387

F(Col) = 57.98

F(Row) = 11.32

\*Estimated value

Table 26. Magnesium concentrations in SET III and SET IV, in mg/l.

Bucket	SET III				SET IV			
	Drain- age	6-year old	New Lab	1-year old	Drain- age	6-year old	New Lab	1-year old
1	0.46	0.48	0.47	0.50	0.48	0.49	0.50	0.49
2	0.52	0.53	0.51	0.51	0.50	0.44	0.46	0.50
3	0.53	0.54	0.48	0.53	0.51	0.48	0.55	0.54
4	0.62	0.59	0.57	0.57*	0.55	0.57	0.62	0.62
5	0.53	0.56	0.56	0.54	0.58	0.61	0.56	0.58
6	0.51	0.51	0.49	0.47	0.57	0.55	0.56	0.64
7	0.51	0.45	0.53	0.54	0.49	0.54	0.54	0.51
8	0.54	0.50	0.48	0.52	0.52	0.52	0.54	0.53
9	0.91	0.73	0.76	0.57	0.89	0.79	0.96	0.99
10	0.75	0.72	0.63	0.80	0.63	0.61	0.56	0.60
Mean	0.58	0.56	0.54	0.55	0.57	0.56	0.58	0.60
Range of LSD								
Upper	0.64	0.61	0.60	0.60	0.62	0.61	0.63	0.65
Lower	0.53	0.50	0.49	0.50	0.51	0.50	0.53	0.54

LSD = 0.053

Z = 0.00396

## Results of Analysis of Variance

Source	Sum of Squares	Degrees of Freedom	Mean Square
Total	1.00840	79	
Column	0.01936	7	0.002766
Row	0.76936	9	0.085485
Residual	0.21571	62	0.003479

F(Col) = 0.79

F(Row) = 24.57

\*Estimated value

Table 27. Calcium concentrations in SET III and SET IV, in mg/l.

Bucket	SET III				SET IV			
	Drain- age	6-year old	New Lab	1-year old	Drain- age	6-year old	New Lab	1-year old
1	5.8	5.7	5.3	5.8	6.0	5.7	6.0	5.8
2	6.0	6.4	5.8	6.2	6.0	5.4	5.6	5.7
3	5.9	6.0	5.5	6.1	6.0	5.9	6.3	5.8
4	6.2	6.1	5.9	6.0*	6.1	5.9	6.7	6.6
5	5.7	5.7	5.6	5.4	5.8	6.0	5.6	5.8
6	5.6	5.6	5.4	5.5	6.9	6.4	6.2	7.0
7	6.3	5.6	6.4	6.1	5.8	6.0	6.3	5.8
8	5.8	5.3	5.2	5.4	5.6	5.5	5.7	5.6
9	8.5	7.2	8.0	5.9	8.9	7.7	9.1	11.0
10	8.0	7.1	7.0	8.2	7.3	6.2	6.6	6.5
Mean	6.4	6.1	6.0	6.0	6.4	6.1	6.4	6.6
<u>Range of LSD</u>								
Upper	6.9	6.6	6.5	6.6	7.0	6.6	6.9	7.1
Lower	5.8	5.5	5.5	5.5	5.9	5.5	5.9	6.0

LSD = 0.53

Z = 0.45240

## Results of Analysis of Variance

<u>Source</u>	<u>Sum of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>
Total	75.64485	79	
Column	2.88322	7	0.411889
Row	50.30620	9	5.589578
Residual	22.00302	62	0.354887

F(Col) = 1.16

F(Row) = 15.75

\*Estimated value



Table 28. Nitrate-nitrogen concentrations in SET III and SET IV, in mg/l.

Bucket	SET III				SET IV			
	Drain- age	6-year old	New Lab	1-year old	Drain- age	6-year old	New Lab	1-year old
1	1.05	1.00	1.06	1.01	1.00	0.96	0.98	0.98
2	1.06	0.99	1.08	1.02	1.02	0.96	0.99	0.98
3	1.07	1.01	1.07	1.04	1.05	0.97	1.03	0.99
4	1.14	0.95	1.03	0.86	0.99	0.90	0.99	1.02
5	1.03	0.99	1.05	0.92	1.00	0.98	0.94	0.96
6	1.08	1.00	1.04	0.92	1.05	1.00	0.98	1.04
7	1.06	0.99	0.96	0.92	1.01	0.98	1.00	1.04
8	1.06*	0.96	1.05	0.95	0.98	0.91	1.02	1.04
9	1.03	0.95	1.00	0.89	0.87	0.82	0.97	1.00
Mean	1.06	0.98	1.03	0.94	0.99	0.94	0.98	1.00
<u>Range of LSD</u>								
Upper	1.09	1.01	1.07	0.98	1.03	0.97	1.02	1.04
Lower	1.02	0.94	1.00	0.91	0.96	0.90	0.95	0.97

LSD = 0.035

Z = 0.04325

## Results of Analysis of Variance

<u>Source</u>	<u>Sum of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Square</u>
Total	0.22408	71	
Column	0.06468	7	0.009240
Row	0.04007	8	0.005009
Residual	0.07606	55	0.001383

F(Col) = 6.68

F(Row) = 3.62

\*Estimated value

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